

**DRAFT AIR SPARGING PILOT TEST WORK PLAN
FORMER ANGELES CHEMICAL COMPANY
FACILITY**

Prepared and Submitted To:

**Department of Toxic Substances Control
1011 N. Grandview Avenue
Glendale, CA 91201-2205**

On Behalf Of:

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DRAFT AIR SPARGING PILOT TEST WORK PLAN

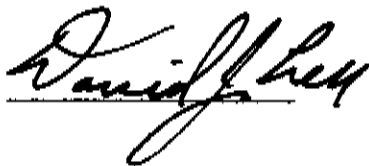
Former Angeles Chemical Company Facility

Prepared and Submitted to:

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1. INTRODUCTION

The Leu Group, on behalf of Greve Financial Services, Inc., has prepared the following Air Sparging Pilot Test Work Plan. This document provides information necessary to conduct a pilot test to evaluate the efficacy of air sparging to treat various volatile organic compounds (VOCs) found in the shallow groundwater at the former Angeles Chemical site.

The former Angeles Chemical Co. facility is located at 8915 Sorensen Avenue, in the City of Santa Fe Springs, California. The property is surrounded by Sorensen Avenue on the east, Air Liquide Corporation to the north and northwest, Plastall Metals Corporation to the north, and a Southern Pacific Railroad easement and McKesson Chemical Company to the south. The former Angeles Chemical facility operated as a chemical repackaging facility from 1976 to 2000. **Figure 1-1** is a Site Location Map. **Figure 1-2** presents an aerial view of the site. The facility covers approximately 1.8 acres and is completely fenced.

1.1 Site Identification

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2.0 PURPOSE

Air sparging (AS) pilot tests are essential to ensure that the design variables which must be determined empirically are properly measured. They also permit the designer to try variations on the basic design to optimize the application to a particular site geology.

The primary objective of a pilot-scale AS test is to evaluate the subsurface response to air injection and extraction. Sufficient time typically is not available to evaluate contaminant fate and removal rates (USACOE, 1997, Leeson et al, 2002). The primary objectives of the pilot test being proposed for the former Angeles Chemical site include the following:

- a) Determine if injected air can reach the vadose zone in the vicinity of the AS wells.
- b) Determine the pressure/flow characteristics at the location of the AS wells.
- c) Determine the duration of groundwater transients during start-up and shutdown.
- d) Determine the zone of influence and the treatment zone around the AS wells

During continuous AS pilot tests data regarding the approximate extent of the zone of influence (ZOI), optimal injection rates and pressures, and off-gas handling considerations can be established. The duration of the expansion and contraction transient phases is also of interest for pulsed AS systems. The selected strategy (pulsed versus non-pulsed) will determine the preferred monitoring techniques and AS mode of operation.

The results of pilot-scale testing may be representative of the physical conditions (e.g., AS air-entry pressure, pressure distribution, air filled porosity) that will occur during full-scale operation, but they may not be predictive of the long-term chemical behavior (e.g., contaminant concentrations and dissolved oxygen (DO) levels) during full-scale AS operations. This is due to the short operational period inherent in pilot tests versus the full scale AS operation.

This work plan is written such that the ZOI will be determined through the use of tracer gases. Helium will be used for the vadose zone air migration evaluation and sulfur hexafluoride (SF_6) will be used for the aquifer air migration evaluation. In addition to ZOI, the subsurface travel times and the efficiency of capture of volatile emissions will be estimated. DO measurements will also be taken but not necessarily relied on. This is because there may be oxygen sinks inherent in the aquifer that may not be overcome due to the short operational period of the pilot test. An example of an oxygen sink is reduced iron (Fe^{++}) that may be present in the groundwater.

An attempt will be made to determine the contaminant extraction levels that are attributable to sparging on a contaminant mass-per-air-volume basis. This will be done by comparing the contaminant extraction level attributed to just soil vapor extraction (i.e., prior to the introduction of air sparging) to the contaminant extraction level with air sparging. This will be done over different air sparging flow rates. Such data may be useful if stable conditions are achieved under each flow rate tested.

3.0 SITE GEOLOGY/HYDROLOGY

Based on the borings and CPT pushes, Shaw (2004) identified six distinct hydrostratigraphic units beneath the former Angeles Chemical site. Uppermost is an "overburden" unit comprising a wide range of materials from fill to silty sands to clayey silts that is designated as "unit A". Next is a well-defined clean sand (sometimes with gravel) horizon designated as "unit B". Following is a fine-grained predominantly silt zone designated as "unit C1" which is underlain by a coarser silty sand zone named "unit D". Next is the finest-grained unit observed, "unit C2" which is predominantly a clayey silt that can be finer (clay) at the top, and coarser (sandy silt) with depth. Finally, "unit E" is a clean coarse sand (similar to unit B) that is considered the top of the regional aquifer system. **Appendix A** provides copies of figures contained in the Shaw (2004) report that graphically show the characteristics and relationships of these hydrostratigraphic units. Included are physical test results from the soil samples collected. Boring logs for MW-11 (Shaw, 2004) and MW-9 (BEII, 2002) are included. These monitoring wells are the closest to the two areas in which the AS pilot test will be conducted.

A perched water zone, which is currently dry, was identified within unit B. The regional aquifer zone from 50' to 80' bgs (referred as the A1 zone) is identified within unit E. A zone of saturation exists between the A1 and the perched water zone and is associated with the unit D sand zone. It is this groundwater that is the subject of this work plan and is referred to as "shallow groundwater" in this document.

Past quarterly groundwater monitoring reports have indicated that monitoring wells MW-6, MW-8, MW-9, MW-10, MW-11, MW-12, MW-16, MW-18, MW-19, MW-22, and MW-26 are screened within the shallow groundwater. Monitoring well MW-4 is noted as a 'first water zone well', but has very little water (0.04 feet) in it. TLG interprets this low value to be due to condensate inside the well that has been trapped in the end cap at the bottom of the well casing. The well is interpreted in this report as being "dry". MW-22 likewise has very little water in it (0.22 feet) and is also interpreted here as being "dry". Only MW-19 had detectable residual free product in it.

In December 2005, the shallow aquifer was measured to be at depths between 29.90 (MW-6) and 38.98 (MW-26) feet bgs (excluding MW-4 and MW-22). A potentiometric groundwater contour map of the shallow groundwater is included as **Figure 3-1**. Groundwater in the A1 zone was measured to be at depths between 37.65 (MW-23) and 42.14 (MW-15) feet bgs. Depths to groundwater and the thickness of water at each shallow groundwater monitoring well are presented in **Table 4-1**.

Hydrographs are included as **Figures 3-2 and 3-3**. Groundwater elevations of both the shallow aquifer and the A1 zone tend to be higher in June and lower in December, which suggests a seasonal recharge in both hydrologic zones. Groundwater levels generally declined from June 2003 to December 2004, interpreted as being due to limited rainfall, which supplies seasonal recharge. The most recent groundwater elevations measured in December 2005 coincide with recent seasonal changes with an decrease in water elevations in 12 wells (mostly in the A1 Zone) and an increase in the first water wells MW-8, -9, -10, 11, 12, 18, and -19.

4.0 PILOT TESTING PROCESS

The basic steps involved in conducting the AS pilot test are described in this section. A pilot testing process checklist that will be used in the field is provided in **Appendix B**. This checklist summarizes key pilot test activities that should be completed in order to confirm air sparging feasibility and obtain the information necessary to successfully design a full-scale air sparging system. This checklist was developed based on the work of Leeson et al. (2002) and was taken from a document entitled "Air Sparging Guidance Document (Naval Facilities Engineering Command, 2001). The checklist is organized by activity (i.e., baseline sampling) and briefly describes the method for data collection and the objective or questions that will be answered by interpretation of the data.

A description of the equipment to be used in the AS pilot test is contained in **Section 5.0**. A discussion on the pilot testing process follows.

4.1 Baseline Sampling

Baseline sampling represents a critical step in the pilot test process. For several of the parameters, it is important to collect data prior to any air sparging activity to ensure that initial conditions are understood. In particular, those parameters include DO, CO₂ and VOC concentrations in groundwater, and soil gas data on VOC, O₂, CO₂ and baseline pressure transducer data recorded with a data-logger.

Since an SVE system is to be used in conjunction with the air sparging system, the SVE system will be operated for a period of time prior to air sparging startup primarily to ensure that the SVE system is operating properly to capture the initial mass loading

anticipated when air sparging is conducted. During this period, SVE off-gas monitoring will be performed for the contaminants of interest in order to establish mass loading from volatilization from the vadose zone compared to volatilization from groundwater. The SVE system, prior to initiating air sparging, shall be operated until the off-gas concentrations have stabilized to the extent that changes in off-gas concentrations due to air sparging operation can be easily determined. Off-gas concentrations will be monitored using a PID at each extraction well.

4.2 Air Injection Flowrate and Injection Pressure

Prior to pilot test activities, it is important to evaluate the expected operating pressure for the air sparging system. This is important both for the selection of the correct air injection system and for the prevention of pneumatic fracturing of the aquifer.

The operating pressure for an air sparging system is determined from the depth of the air sparging well below the water table and the permeability of the aquifer. The minimum injection pressure necessary to induce flow (P_{min} [psig]) is given by:

$$P_{min} \text{ (psig)} = 0.43 H_h + P_{packing} + P_{formation} \quad (1)$$

The pressure at which fracturing of the aquifer can occur is given by:

$$P_{fracture} \text{ (psig)} = 0.73 D \quad (2)$$

Where H_h = depth below the water table to the top of the injection well screened section (e.g., the hydrostatic head in ft); $P_{packing}$ and $P_{formation}$ = air entry pressures for the well annulus packing material and the formation (in psig); and D = depth below ground surface to the top of the air injection well screened interval (in ft).

For typical air sparging wells and applications, $P_{packing}$ and $P_{formation}$ are small compared to the contribution from the hydrostatic head. Air entry pressures are generally <0.2 psig for sands, <0.4 psig for silts, but may be >1.5 psig in some clayey settings (Leeson et al, 2002). At start-up, it is not unusual for users to exceed P_{min} by as much as 5 to 10 psig to initiate flow quickly. The injection pressure then generally declines to about P_{min} as steady flow conditions are approached. Pressures in excess of $P_{fracture}$ can cause fracturing of the formation; however, as the pressure drops off rapidly away from an injection point, the extent of fracturing in most cases is expected to be limited to the area immediately surrounding the well.

To establish the maximum pressure to operate the air sparging system to avoid fracturing of the aquifer, the US Army Corps of Engineers (USACOE, 1997) recommends that a 40% safety factor be used. Therefore:

$$P_{\max} = 0.6 P_{\text{fracture}} (\text{psig}) \quad (3)$$

This pilot test will be operating at two locations within the former Angeles Chemical site. As discussed in **Section 6.0**, the first pilot test location is called Area A and is near MW-9 (**Figure 6-1**). Here the depth to groundwater is ~33.5 feet bgs and the top of the injection well screened section will be ~45 feet bgs (i.e., near the base of the shallow groundwater). Using the formulas provided above, this yields a nominal air sparging pressure range of 4.9 psig to 14.7 psig. The second location is near MW-11 and is called Area B (**Figure 6-1**). Here the depth to groundwater is ~32.7 feet, the top of the injection well screened section will be near the base of the aquifer at ~39 feet bgs. For this area, this yields an effective air sparging pressure range of 2.2 psig to 14.8 psi.

As part of the initial shakedown of the air sparging system, the air injection system will be tested. During this process, both the air flowrate and the injection pressure will be measured to ensure that neither P_{\min} nor P_{\max} are violated at the required air flowrate. For this pilot test, an oil-less compressor will be used because it eliminates uncertainties relating to air flowrate and potential overheating.

The flow rate to the air sparging wells is controlled through a "vent valve" in the injection air line. This valve will be fully open to begin the test and then will be slowly closed while monitoring the increase in pressure and flowrate up to the desired flowrate. During this process, care will be taken not to exceed the upper pressure limit for the system (as determined by the calculations described above).

It is desirable to begin the test with an air injection flowrate of 15 ft³/min. The air injection pressure at the on-set of flow will be recorded, as well as pressures every 5 to 10 minutes until the pressure and flow stabilize.

4.3 Groundwater Pressure Measurements During Air Sparging Startup and Shutdown

Once the flow and pressure conditions for sparging have been established, groundwater pressures during air sparging startup and shutdown can be determined. The primary objective of this test is to assess the time required for airflow distribution to come to steady state. As discussed by Johnson et al. (2001), pressure measurements provide an easy and sensitive means of assessing if AS air is stratigraphically trapped below the water table. The pressure measurements can also provide a measure of site permeability, based on the magnitude of the response. In general terms, during air sparging startup groundwater pressures will increase because air is being pushed into the formation faster than the water can move away from the air sparging well. Typically, as long as the volume of air below the water table is increasing, the groundwater pressure will remain above pre-air sparging levels.

As a result, the time required for groundwater pressure to return to pre-air sparging values is a good measure of the time required for the macro-scale air distribution to come to steady state. For media which are relatively homogeneous with respect to air flow (e.g., uniform sands), the time required for air sparging pressures to return to pre-air sparging values will generally be measured in tens of minutes to a few hours. If the site is stratified with lower-permeability layers, then the groundwater pressure may remain elevated for tens of hours to days.

The magnitude of the groundwater pressure response can be from millimeters to a few meters of water. In general, if the injection rate is on the order of 20 ft³/min and the response is on the order of tens of centimeters and responses of a meter or more may occur in finer-grained media or in media where the air is stratigraphically confined (Leeson et al. 2002)

Generally, at sites where groundwater pressures remain elevated by more than a few tens of centimeters for more than 8 hours, it can be assumed that the air distribution is controlled to a high degree by the structure of the aquifer, and it will be important to determine if the air is being delivered to the treatment zone in an effective manner.

In this pilot test, groundwater pressure will be recorded using downhole pressure transducers and data loggers. The monitoring wells will be 2-inch piezometers as described in **Section 6.2** and spaced as shown in **Figure 5-1**.

4.4 Helium Distribution and Recovery Test

Helium can be used in two primary ways as a tracer for air sparging systems (Johnson et al., 2001; Leeson et al, 2002). The first is to assess the effectiveness with which the SVE system is capturing the air sparging air. The second method is to identify the locations at which air sparging air moves from the groundwater zone to the unsaturated zone. Described in **Appendix C** are the methods for assessing recovery of air sparging air by an SVE system and for evaluating air sparging air distribution at the water table. One of the strengths of the tracer test is that it can be easily repeated, usually with delays of only a few hours or so between them. This allows the effects of process changes (e.g., distribution of air flow from various wells) to be quickly assessed.

Helium is the most common tracer gas used, since it is relatively inexpensive, readily available, and analytical instrumentation is available for field use. Typical field instrumentation is a Marks Product helium detector. The detector can detect helium concentrations from 0.1% to 100%. It is factory calibrated, so it cannot be calibrated in the field, but checks will be made with helium standards to verify the instrument is operating properly. Vapor samples will be collected in Tedlar™ bags or canisters. The helium detector is then attached directly to the sample container for measurement.

The procedures for conducting the helium tracer gas study are provided in **Appendix C**.

4.5 SVE Off Gas Sampling

SVE off gas samples will be collected at the sample port located on the exhaust stack of the secondary carbon vessel. A Tedlar™ bag will be attached to the sample port and allowed to fill with off gas. Once the Tedlar™ bag has filled with off gas the Tedlar™ bag will be disconnected from the sample port. The Tedlar™ bag will then be placed in a cooler for safe keeping prior to analysis.

4.6 Dissolved Oxygen Monitoring

Dissolved oxygen data has the potential to identify the zone where oxygen is being delivered by the air sparging system. If the baseline measurements shows low dissolved oxygen concentrations (e.g., less than 2 mg/L), it may be possible to identify areas where air sparging has resulted in increases in DO. Given the historic DO concentrations reported in quarterly groundwater monitoring reports, this is anticipated to be the case.

To determine the impacts of air sparging, DO will be measured in all groundwater monitoring points immediately before and following the pilot test. Unfortunately, several factors can complicate the interpretation of DO. First, at many sites where active biodegradation is ongoing, there may be significant quantities of reduced species (e.g., Fe(++)) that act as rapid sinks for oxygen and that mask oxygen delivery to that region. Second, microbial activity may be high, effectively consuming oxygen as fast as it is delivered to the area. Finally, care must be taken to avoid artifacts caused by air entry into monitoring wells and preferential aeration within the well. This is an important part of the reason why short-screened monitoring wells in the treatment zone will be used for the pilot test.

4.7 SF₆ Distribution Test

In this test, sulfur hexafluoride or SF₆ is used as an analog for oxygen to determine the distribution of air in the groundwater zone (Leeson et al., 2002). SF₆ has a water solubility that is similar to oxygen; however, SF₆ has several advantages over oxygen and as a result the test can be both more sensitive and more quantitative. These advantages include:

- 1) It does not occur naturally, so background concentrations are essentially zero;
- 2) SF₆ can be detected at extremely low concentrations in water and air, thus it is a much more sensitive tracer than oxygen; and
- 3) It is not biodegradable, so it acts as a conservative tracer to show where the air was delivered.

To conduct the test, SF₆ will be blended with the injection air stream at a known concentration for a period of 12 to 24 hours. The objectives in injecting for a short, known period are:

- 1) To provide an opportunity for SF₆ transfer from the air to the groundwater without a significant amount of groundwater transport; and
- 2) To allow an estimate of the mass transfer coefficient at various locations to be determined.

The details of these procedures are contained in **Appendix D**. In overview, at the end of the SF₆ injection period, groundwater samples are collected and analyzed for SF₆. The duration of SF₆ injection and the cumulative volume of groundwater sample will be recorded. Based on the concentration of SF₆ in the injected air, and the Henry's Law constant for SF₆, the percent saturation of SF₆ in the groundwater sample will be determined. In general, those concentrations can be divided into three groups.

The first are values approaching saturation (e.g., >40% of theoretical solubility). These generally indicate that the sample location lies within the "zone of aeration" of the air sparging system. The second group contains samples with low concentrations of SF₆ (e.g., <10%) and indicate that an air channel may be in the vicinity of the sampling location (e.g., it may be within the "zone of treatment"), but the air saturation in the aquifer at that point is probably low. The third group is composed of samples that have no SF₆ present. These samples are presumed to lie outside both the aeration and treatment zones.

In the context of site-specific air sparging program, to be sufficiently conservative, the spacing of the air sparging wells may need to be based on the size of the zone of aeration. Thus, for example, if high concentrations of SF₆ are observed at a distance of 15 ft, but not at 20 ft, then a well spacing of up to 30 ft might be appropriate, but greater than that may not be justified.

4.8 Other Qualitative Observations

Often during pilot tests there are operational factors that are readily noticed and that are important to the viability of air sparging. Therefore, any qualitative indicators of air distribution, such as bubbling or gurgling noises in wells, water "fountaining" out of monitoring points, etc. will be recorded.

5.0 PILOT TEST EQUIPMENT

The following equipment is needed to conduct the pilot test activities for each area to be tested:

- a) 1 air injection well equipped with a well-head pressure gauge, flowmeter, and valve;
- b) 1 air injection compressor;
- c) 6 Groundwater monitoring wells equipped with water-level pressure transducers and data loggers;
- d) 12 Groundwater and vadose zone multi-level monitoring points;
- e) Helium tracer gas feed and monitoring system;
- f) SF₆ tracer gas feed and monitoring system;
- g) 2 Vapor Extraction wells and
- h) 1 SVE system.

The pilot test layout for test areas A and B are shown in **Figure 5-1**. In designing the monitoring layout, it has been recognized that air distributions often have unpredictable preferred directions, and therefore a spatially distributed monitoring network is preferred over installations having monitoring points emanating out from the injection well in a line in one or two directions. Past investigators recommend the monitoring network should extend out at least a distance equal to one-half to three-fourths of the well-spacing distance contemplated in the conceptual design (Leeson et al, 2002). In the conceptual design contained in the Draft RAW, AS well spacing of between 35 and 40 feet was used. Therefore, in the proposed pilot test, the furthest well distance is 25 feet. A discussion on each pilot test area is contained in **Section 6.0**. A discussion on the pilot test equipment follows.

5.1 Injection Well

The air injection well will be similar to that envisioned for full-scale implementation. A typical air injection well is a 1- to 4-inch-diameter vertical well having a 1- to 2 ft-long screened interval. For this pilot test, a 2-inch-diameter well with a 2 foot long screened interval will be used.

Free product floating on groundwater (LNAPL) has been found at the former Angeles Chemical site and is currently being removed from the last known area at MW-19. The concentrations of VOCs in the dissolved phase of groundwater are orders of magnitude less than saturation levels, therefore, the presence of free phase DNAPLs along the bottom of the shallow aquifer is not expected.

Injection wells can be installed using hollow-stem auger drilling or direct push technology. Direct-push installed injection wells are considered to be superior for preventing annular-space short-circuiting and will be used here. The injection well screen will be connected to a riser with care taken to prevent air leakage at joints. The wellhead will be completed with a tee, allowing air injection from the side and a threaded plug on the top to allow ready access to the well for sampling or gauging. A check valve will be necessary for pulsed injection to prevent backflow up the well following shutdown.

For this site, air sparging injection wells will be installed inside a 2.25-inch OD drive rod pushed to the required depths of 45.5- and 40-feet bgs (Areas A and B, respectively). An off-the-shelf, pre-packaged (or "pre-packed") well screen, with a 0.81- inch OD will be threaded onto 1.0-inch Schedule 40 PVC pipe rising to the surface completion. The sand pack around the pre-packed well screen will be 2/12 grade sand. Once the well screen and riser has been assembled and lowered to depth, the drive rod will be retracted. Additional 2/12-grade sand will be emplaced to fill in the annular space around the pre-pack and to a point 3 feet above the well screen. A 2-foot-thick bentonite seal will be emplaced above the sand pack. This seal will prevent grout, which fills up the remainder of the annulus to the surface, from entering the well screen. The well will be sealed and grouted according to EPA and ASTM D-5092 method requirements. Flush-mount, traffic-rated well boxes will be used.

The primary considerations for injection well construction are the depth to the top of the screened interval and the prevention of annular space short-circuiting. Practitioners have installed a variety of screen lengths and depths to the top of the screen. Screen length appears not to be a primary design consideration, as research indicates that air generally escapes within a very short interval near the top of the screen. Screen type also does not appear to be a significant design consideration, as pore size distribution in the formation controls airflow. A 0.6 m (two foot) length of continuous wrap well screen is generally considered to be acceptable (USACOE, 1997) and will be used here.

5.2 Air Injection Compressor

The air injection compressor will be a portable rotary screw compressor rated for 110 cfm at 100 psi. The compressor is direct driven by a 59 HP diesel engine.

At the discharge of the portable compressor a 1" steel pipeline is provided for the purpose of flow regulation and flow measurement. This pipeline will contain a tee that a 1" globe valve will be put into and vented to atmosphere (allowing air to blow off to atmosphere). This valve will provide a manual means for the operator to adjust the flow delivered to the air sparging wells as discussed in **Section 4.2**. Downstream of this tee, provision in the pipeline will be made to insert the probe of a flow measuring anemometer.

To protect the air injection compressor, incoming air will be filtered down to a particulate size of 10 micron going into the compressor. The compressor is protected also from high discharge temperature while the engine is protected against high coolant temperature and low engine oil pressure. Backflow prevention (through compressor and system) is provided by a discharge check valve.

The engineering drawings of the compressor and the SVE system to be used are shown in **Figures 5-2 through 5-8**.

5.3 Groundwater Monitoring Wells

The piezometers and groundwater sampling points will be screened only within the target treatment zone. The monitoring networks will be installed with direct-push methods. Small diameter (1/4- to 3/8-inch) discrete (6- to 20-inch length) direct push implants will be used for the groundwater and vadose zone monitoring points.

5.4 Groundwater and Vadose Zone Monitoring Points

There are few available guidelines regarding the location of monitoring probes associated with a given injection well. However, injection well spacings ranging from 3.7 to 15 m (12 to 50 ft) have been reported in the literature (Wisconsin DNR 1993). Therefore given a potential ZOI of 1.8 to 7.6 m (6 to 25 ft), monitoring probes should be located at distances less than 1.8 to 7.6 m in order to provide useful design data. Positioning monitoring points in various directions and at various distances from IAS points, as well as at various depths of interest will enhance the data quality obtainable from the pilot test. Past investigators have recommended that, as a minimum, there should be at least three monitoring points in the saturated zone, spaced from 1.5 m from the injection well, out to a distance equal to two times the depth of the sparge point screen below the water table (USACOE, 1997).

For this pilot test, the location and spacing for the monitoring points are shown in **Figure 5-1**. As shown, the monitoring point radiate from the air sparge well at distances of 1.5 m, 3 m, 4.5 m, and 7.5 m. This type of design has been successfully used by past investigators (Leeson, et al, 2002; Cristin et al, 2001)

5.5 Soil Vapor Extraction System

The Soil Vapor Extraction (SVE) System will be rated for 250 cfm at a maximum vacuum level of 8" Hg. A rotary positive vacuum pump driven by a 10 hp electric motor will provide the airflow and vacuum required.

At the inlet to the SVE system flow from the wells will be regulated with a manual dilution air valve which is located downstream of the inlet connection to the wells. The manual valve is a 2" gate valve and an air filter is provided on the valve inlet. Upstream of the dilution air valve is provision in the inlet piping for collecting flow rate measurements, air samples and vacuum measurements.

The vacuum pump will be protected from particulates and water by a multi-stage filtration system. The first stage of this filtration system is a gas liquid separator (GLS) responsible for removing any large water mass or slug entrained in the inlet air stream. The second stage is the demister section which is designed to remove water droplets from the air stream down to 10 micron. The GLS also provides 20 gallons of liquid storage for

any liquid removed from the air stream. The final filtration stage is a media filter designed to remove any particulate down to 10 micron. The vacuum pump is fitted with a discharge silencer that will reduce noise levels to a maximum of 90 dBA at three feet.

Liquid from the GLS is removed from the separator by an electric motor driven water pump. The pump is controlled either in the "HAND" mode by the operator or in the "AUTO" mode by level switches mounted within the separator.

The discharge of the blower is destined for volatile organic compound clean-up by carbon adsorption. However due to the heat of compression, by the vacuum pump, the discharge air stream from the vacuum pump will first be cooled for effective use of the activated carbon.

The discharge air stream is cooled with the use of an air-to-air heat exchanger. An electric motor driven fan pulls ambient air over the heat exchanger tube and fin core having a capability of cooling to within ten degrees of ambient temperature. A variable frequency drive provides power and speed control for the fan motor and along with a temperature control loop will provide temperature set-point control. Targeted temperature set-point exiting the heat exchanger is 100 Deg F.

Two one thousand pound vapor phase carbon vessels shall be arranged in series for VOC removal from the air stream. Sampling ports will be provided on the inlet and outlet of each carbon vessel. Temperature and Pressure instrumentation will be provided on the inlet of the primary carbon vessel.

The engineering drawings of the compressor and the SVE system to be used are shown in **Figures 5-2 through 5-8.**

6.0 PILOT TEST AREAS "A" AND "B"

Because of known lithology changes across the site, two locations have been chosen to conduct the pilot tests. The two areas are show in **Figure 6-1**. The first test area (Area A) will be located near MW-9 in the northeastern corner of the facility. This area has been chosen because is represents a portion of the site where the shallow aquifer lies within a trough (Shaw, 2004). The rise along the sides of the trough may have an impact on the ZOI. By placing a test area in this location, we hope to be able to assess such an impact and account for it in the placement of air sparging wells for the full-scale remediation program. An additional reason for selection of this area is the thickness of the aquifer is near its maximum at this location.

The second test area (Area B) is located near MW-11 along the central western side of the facility. This area represents those portions of the site which are not located within or along the troughs which are characteristic of unit-D. As noted in the Shaw (2004) report,

the shallow groundwater is affiliated with unit-D. Another reason for selection of this area is that the thickness of the aquifer is near its minimum at this location.

The location of the various wells and monitoring points within each test area is shown in **Figure 5-1**. The well location configuration that will be used at the former Angeles Chemical site is based on the configuration that has been successfully used at various other sites and was initially created by Johnson, Hinchee, Leeson and others during a Navy pilot test program located in Port Hueneme, California (Leeson et al, 2002). The well location configuration recognizes that subsurface air distributions are often unpredictable in their preferred directions. A straight line of monitoring wells could miss the air-impacted zone entirely. Therefore, a three dimensional monitoring pattern is preferred.

The sparge well will be installed in the center of the test area. The design and operations have been discussed in **Section 5.0**.

Twelve multi-level sampling points will be used to collect groundwater and soil vapor samples and will consist of a bundle of 0.32-cm inner diameter (ID) (1/8-inch) color-coded, stainless steel sampling lines inside of a 2-inch PVC riser. Three tubes will terminate near the bottom, mid-point and top of the aquifer, respectively. Within the vadose zone, the terminus of the tubes will be spaced every five feet, starting just above the capillary fringe. Groundwater or air samples will be collected through the steel tubes, which will be "PVC-welded" to the 100-mesh stainless steel screen. **Figure 6-2** shows a construction diagram of the multi-level sampling device. The multi-level monitoring points will be installed via direct push methods. Soil vapor extraction wells will be 2-inch-diameter PVC (5-ft casing, 5-ft screened interval) installed to a depth of 30 ft bgs, packed with sand, a hydrated bentonite seal, and bentonite slurry to the surface.

Within each test area five piezometers and one existing groundwater monitoring well will be equipped with pressure transducers and data-loggers to log changes in groundwater elevations. A construction diagram of the piezometers is provided in **Figure 6-3**.

Two vapor extraction wells will be used to collect, measure and treat gases collected during the pilot test. A construction diagram of the vapor extraction well is provided in **Figure 6-4**.

7.0 PILOT TEST REPORT

Once the fieldwork for the pilot test is completed, the laboratory reports received, and the data analyzed and interpreted, a pilot test report will be written and submitted to DTSC. The pilot test report will consist of text, figures and tables. Specifically, the report will include:

- General discussion describing the test and a discussion of the hydrogeological conditions at the site.
- Discussions on the design of the sparging wells include the screen length and diameter, slot size, depths and specification of the filter pack and seals, bore hole diameter, and the drilling method.
- A discussion of the airflow rates that were injected and extracted during the test and how the contaminant concentrations in the soil venting system changed with differing air injection rates. The ratio of extracted to injected airflow rates will also be include.
- The zone of influence will be estimated, including a discussion how the estimate was determined and what field data was used to make the estimate.
- Conclusions will be provided regarding the efficacy of air sparging at the former Angeles Chemical site, including the design, well placement and spacing, number of wells, pressure and air flow requirements for the air compressor, and any other pertinent details.
- Any other observations.

Figures will include:

- A graph indicating the pressure and air flow characteristics of the air sparging wells that were tested.
- Geologic cross section(s).
- A map of the site drawn to scale, including:
 - Locations of the sparging wells,
 - Locations of the air extraction wells,
 - Paved areas, buildings, and structures that may act as a
 - Surface seal or an infiltration barrier;
 - Buried utility trenches that may act as zones of higher permeability;
 - Identification the contaminant types at each test location),
 - Zone of soil contamination,
 - Zone of groundwater contamination,
 - Scale, north arrow, title block, site name, and key or legend,
 - Any other pertinent site information.
- A water table map prior to, during and shortly after of the pilot test.
- An iso-concentration map with groundwater dissolved oxygen levels before and after the pilot test;
- A map showing the conceptual layout of a full scale AS/SVE system, assuming that the pilot test documents the efficacy of such a system.

Tables will include:

- Water levels/elevations and dates of measurements in monitoring wells.
- Field data, including times of readings, airflow rates, injected air temperature, and injected air pressure.

Appendices will include:

- Complete discussion of field procedures for the test.
- Boring log and construction diagram for sparging well(s) and extraction well(s).
- Calculations determining the hydraulic conductivity and natural groundwater migration rate.
- Laboratory reports.

8.0 RELIANCE

This report was prepared by The Leu Group solely for the use and benefit of Greve Financial, Inc. Greve Financial, Inc. may release this information to third parties, who may use and rely upon this information at their discretion. However, any use of or reliance upon this information by a party other than Greve Financial, Inc. shall be solely at the risk of such third party and without legal recourse against members of The Leu Group Team; its subsidiaries and affiliates; or their respective employees, officers, or directors; regardless of whether the action in which recovery of damages is sought is based upon contract, statute, or otherwise. This information shall not be used or relied upon by a party which does not agree to be bound by the above statement.

This report has been prepared in accordance with generally accepted practices using standards of care and diligence normally practiced by recognized consulting firms performing services of a similar nature. The members of The Leu Group are not responsible for the accuracy of information

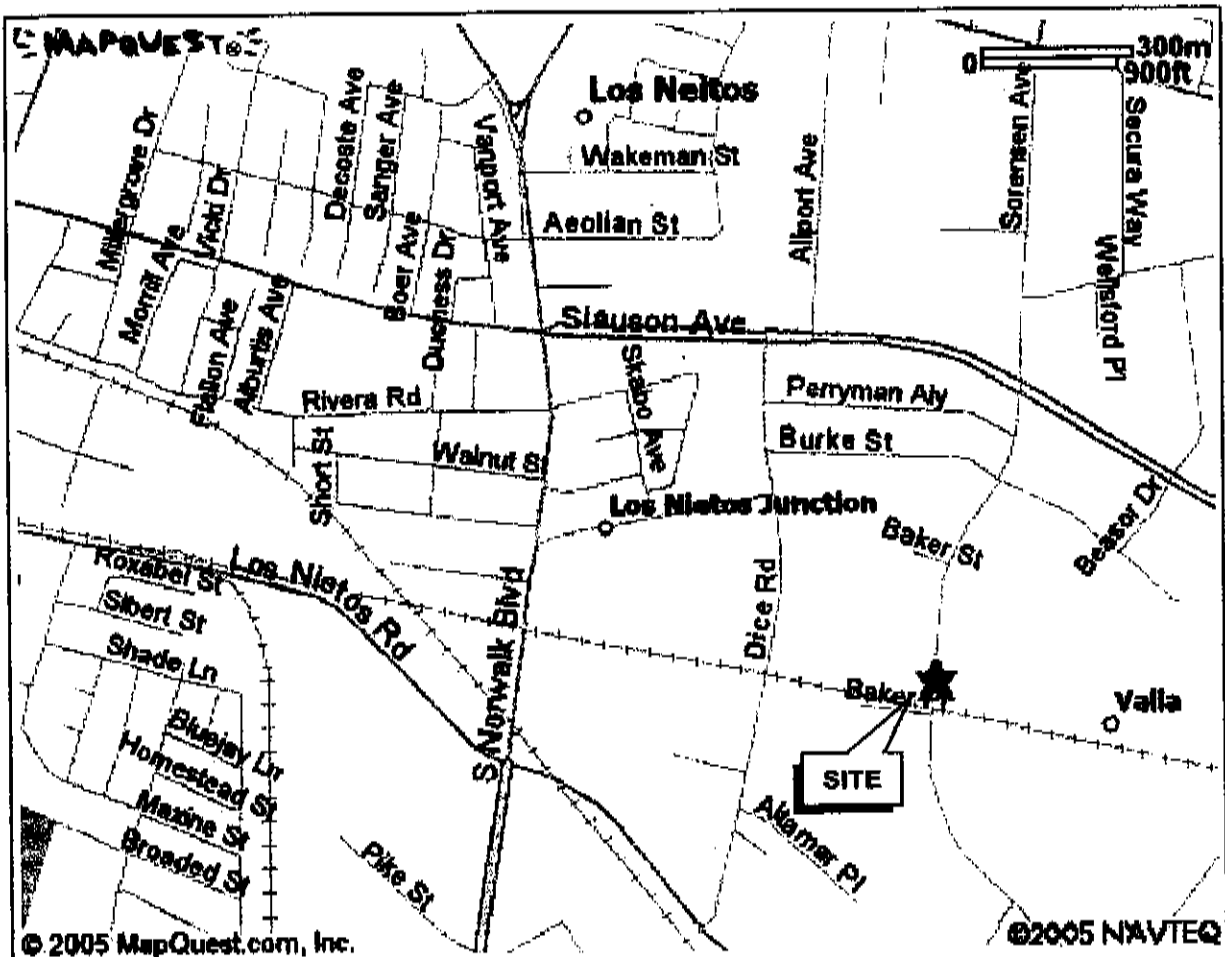
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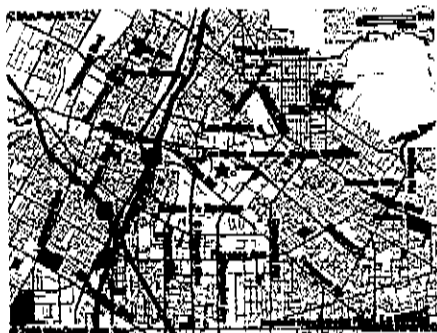
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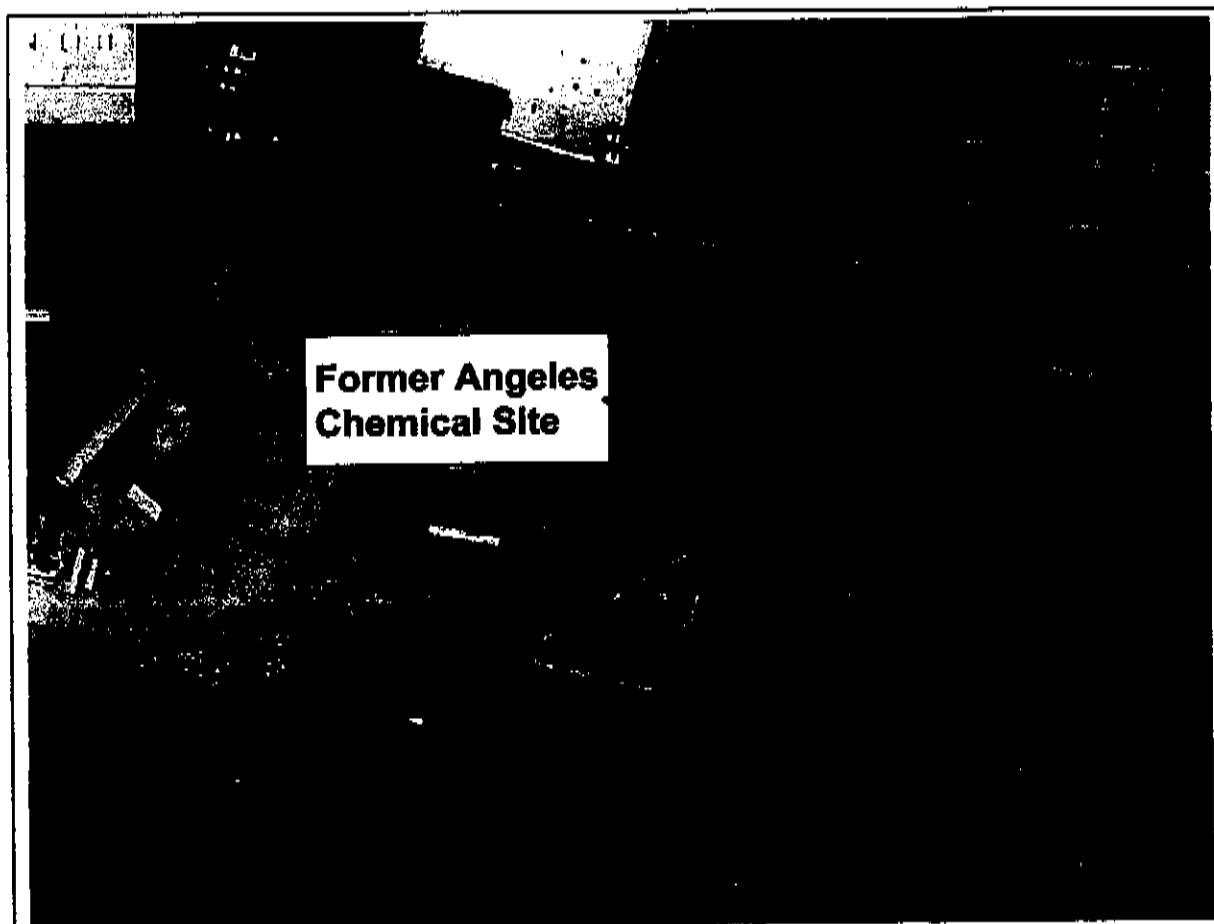
FIGURES



SOURCE: Map Quest

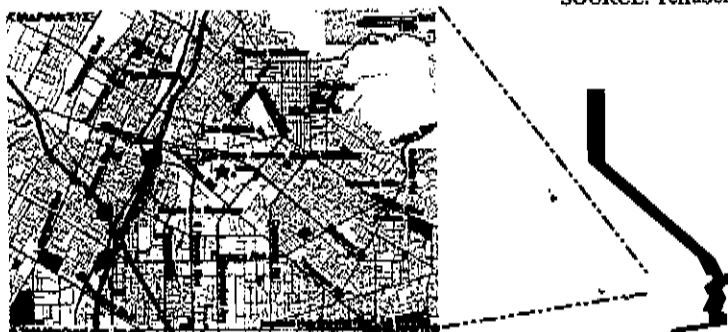


<p>THE LEU GROUP</p> <p>33725 MAGELLAN ISLE MONARCH BEACH, CA 92629 PHONE: (949) 248-5873 FAX: (949) 248-8785</p>	<p>SITE LOCATION MAP</p> <p>FORMER ANGELES CHEMICAL SITE 8620 Sorensen Avenue, Santa Fe Spring CA</p>	<p>Figure:</p> <p>1-1</p> <p>Project: Greve AS Pilot Test</p>
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**Former Angeles
Chemical Site**

SOURCE: TerraServerUSA: <http://terraServer.microsoft.com>



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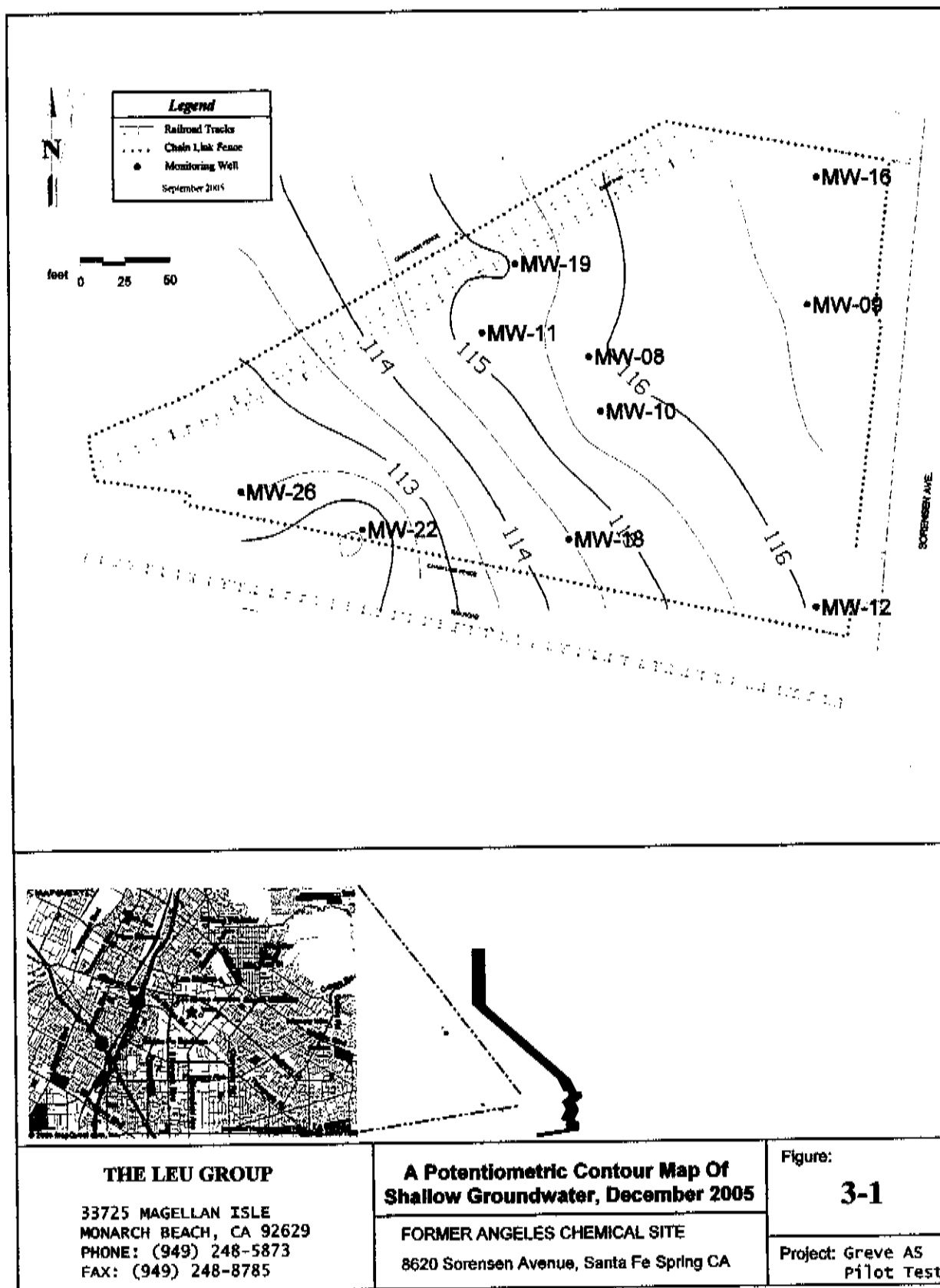
**SITE LOCATION AERIAL PHOTO
March 29, 2004**

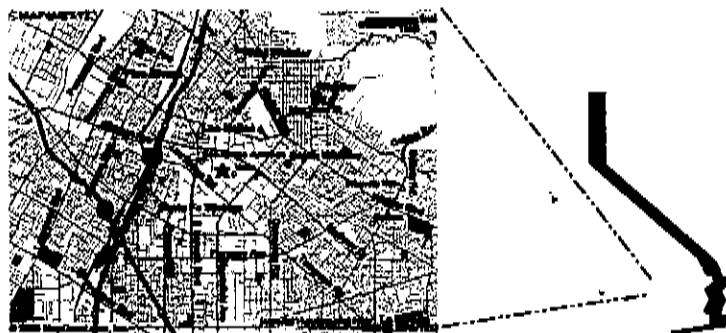
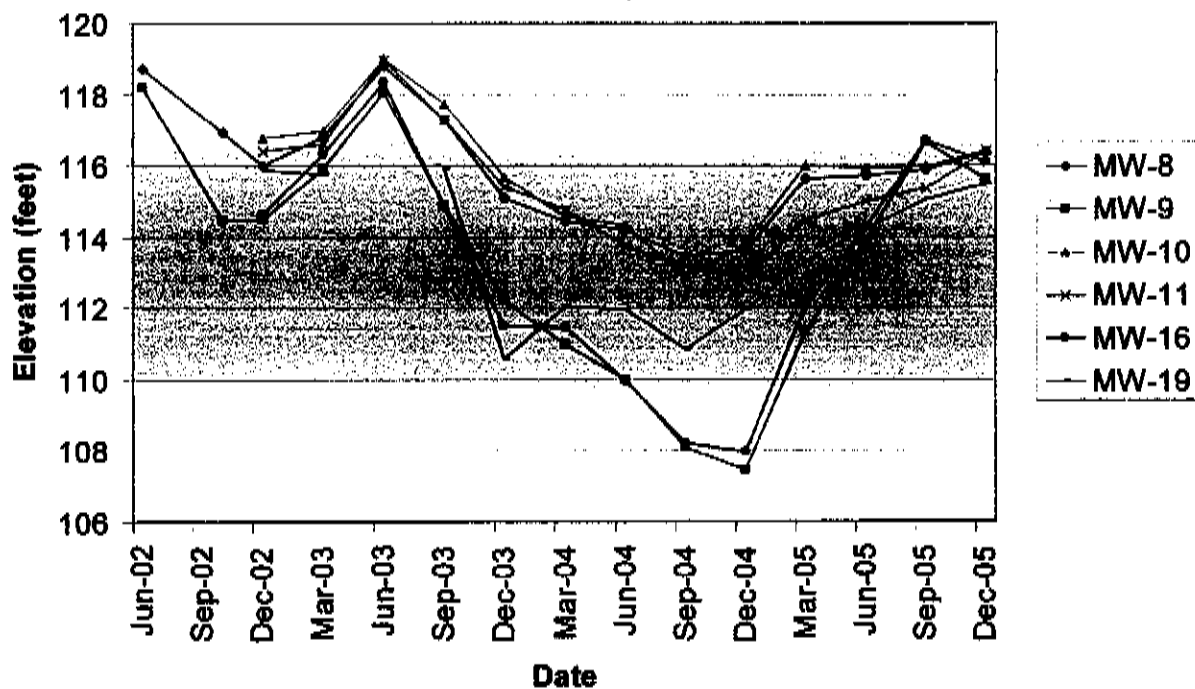
FORMER ANGELES CHEMICAL SITE
8620 Sorensen Avenue, Santa Fe Spring CA

Figure:

1-2

Project: Greve AS
Pilot Test





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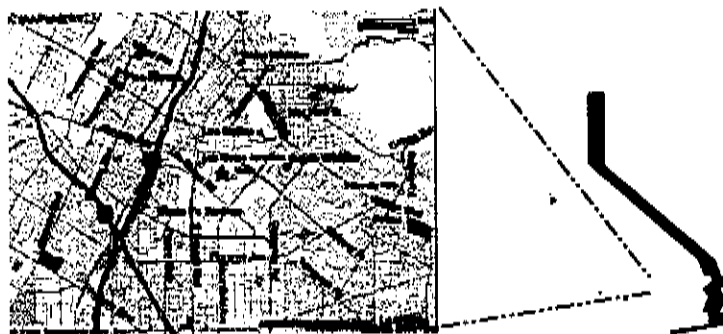
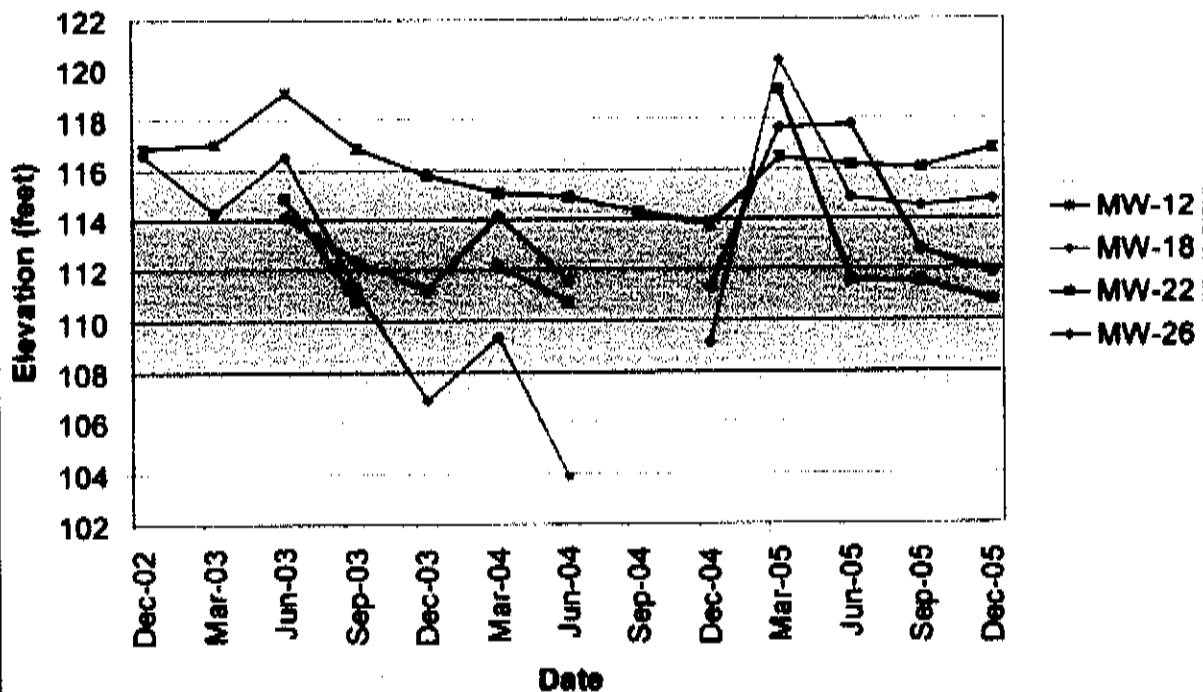
Shallow Groundwater Elevations From Central & Northern Wells

FORMER ANGELES CHEMICAL SITE
8620 Sorensen Avenue, Santa Fe Spring CA

Figure:

3-2

Project: Greve AS
Pilot Test



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Shallow Groundwater Elevations From Southern Wells

FORMER ANGELES CHEMICAL SITE
8620 Sorensen Avenue, Santa Fe Spring CA


Figure:

3-3

Project: Greve AS
Pilot Test

SYMBOL SPECIFICATION

INSTRUMENTATION:

INSTRUMENT TYPE —  — SYSTEM POSITION NUMBER



REFERENCE POINT FOR DESIGN ONLY
NOT ACTUAL INSTALLED INSTRUMENT.
OPTIONAL FIELD MOUNTED INSTRUMENT
TO BE INSTALLED AT THIS LOCATION
IF CHOSEN.



LOCAL MOUNTED INSTRUMENT



INSTRUMENTS WITH INPUTS OR OUTPUTS
AT THE SITE CONTROL PANEL



PILOT LIGHT OR ALARM INDICATOR



PLC FUNCTION

SYSTEM DESIGNATION:

ASW	AIR SPARGE WELL & MANIFOLD
VEW	VAPOR EXTRACTION WELL & MANIFOLD
DPW	DUAL PHASE WELL & MANIFOLD
ERW	ELECTRIC RECOVERY WELL & PUMP
PRW	PNEUMATIC RECOVERY WELL & PUMP
VER	VAPOR EXTRACTION REGENERATIVE BLOWER
VEP	VAPOR EXTRACTION POSITIVE DISPLACEMENT
ASV	AIR SPARGE ROTARY VANE COMPRESSOR
ASB	AIR SPARGE POSITIVE DISPLACEMENT BLOWER
DPO	DUAL PHASE SEALED LIQUID RING PUMP
DPL	DUAL PHASE LIQUID RING PUMP
DPB	DUAL PHASE POSITIVE DISPLACEMENT BLOWER
OW	OIL - WATER SEPARATOR SYSTEM
STL	AIR STRIPPER LOW PROFILE
VC	VAPOR PHASE CARBON
LC	LIQUID PHASE CARBON

EQUIPMENT DESIGNATION:

B	BLOWER
C	COMPRESSOR
FLT	FILTER
HEX	HEAT EXCHANGER
M	MOTOR
P	PUMP

INSTRUMENT TYPE/DESIGNATION:

CP	CAPACITIVE SENSOR/PROBE
FE	FLOW ELEMENT
FI	FLOW INDICATOR
FIR	FLOW INDICATING RECORDER
FM	FLOW METER
FQI	FLOW METER (TOTALIZING)
FS	FLOW SWITCH
HS	HAND SWITCH
LAH	LEVEL ALARM HIGH
LAHH	LEVEL ALARM HIGH HIGH
LAL	LEVEL ALARM LOW
LSH	LEVEL SWITCH HIGH
LSHH	LEVEL SWITCH HIGH HIGH
LSL	LEVEL SWITCH LOW
LSLL	LEVEL SWITCH LOW LOW
LSM	LEVEL SWITCH MIDRANGE
PAH	PRESSURE ALARM HIGH
PAL	PRESSURE ALARM LOW
PC	PRESSURE CONTROL
PDAH	PRESSURE DIFFERENTIAL ALARM HIGH
PDI	PRESSURE DIFFERENTIAL INDICATOR
PDS	PRESSURE DIFFERENTIAL SWITCH
PDT	PRESSURE DIFFERENTIAL TRANSMITTER
PI	PRESSURE INDICATOR
PS	PRESSURE SWITCH
PSH	PRESSURE SWITCH HIGH
PSL	PRESSURE SWITCH LOW
S	SAMPLE PORT
TAH	TEMPERATURE ALARM HIGH
TAL	TEMPERATURE ALARM LOW
TC	TEMPERATURE CONTROLLER
TE	TEMPERATURE ELEMENT
TI	TEMPERATURE INDICATOR
TIC	TEMPERATURE INDICATING CONTROLLER
TIR	TEMPERATURE INDICATING RECORDER
TSH	TEMPERATURE SWITCH HIGH
TSL	TEMPERATURE SWITCH LOW
TT	TEMPERATURE TRANSDUCER
VFD	VARIABLE FREQUENCY DRIVE
YC	EVENT CONTROL
YO	EVENT OPEN
ZAO	POSITION ALARM OPEN

DRAWING NOMENCLATURE

1. UNDER NOTE SECTION, NOTE WITH BOX
IS IDENTIFIED ON THE DRAWING WITH
CORRESPONDING NUMBERED BOX.

THE LEU GROUP			PROJECT: AS PILOT TEST		
33725 MAGELLAN ISLE MONARCH BEACH, CA 92529 PHONE: (949) 248-5673 FAX: (949) 248-6788			SITE LOCATION: FORMER ANGELES CHEMICAL SITE 8620 SORENSON AVENUE SANTA FE SPRINGS, CA		
TITLE: SYMBOLS AND LEGEND SHEET SYMBOL SPECIFICATIONS					
REV	DATE	NAME	FIGURE NO.	SHEET NO.	SHEET SIZE
0	03/20/2008	RHG	5-2	1 OF 7	A
SCALE: NTS					

PIPING AND PIPING COMPONENT SYMBOLS

CONTROL VALVE BODIES:

	BALL VALVE
	GATE VALVE
	GLOBE VALVE
	BUTTERFLY VALVE
	SWING CHECK VALVE
	DIAPHRAGM VALVE
	BALL CHECK VALVE
	NEEDLE VALVE
	3 WAY VALVE
	4 WAY VALVE
	FOOT VALVE

ACTUATORS & REGULATORS:

	GEAR ACTUATOR
	PRESSURE RELIEF
	DIAPHRAGM ACTUATOR
	HYDRAULIC ACTUATOR
	SOLENOID ACTUATOR
	MOTOR ACTUATOR
	DIGITAL ACTUATOR
	WATER ACTUATOR
	REGULATOR
	FLOW INDICATOR
	PRESSURE OR VACUUM RELIEF VALVE

FLOW MEASURING DEVICE SYMBOLS:

	SINGLE PORT PITOT TUBE
	AVERAGING PITOT TUBE
	POSITIVE DISPLACEMENT FLOW INDICATOR
	VORTEX SENSOR
	SONIC FLOW METER
	ROTAMETER FLOW INDICATOR
	TARGET TYPE SENSOR
	WEIR
	VENTURI TYPE FLOW ELEMENT
	FLOW NOZZLE
	ORIFICE PLATE FLOW ELEMENT

FITTINGS & PIPING

	VICTAULIC CONNECTOR
	FLANGED CONNECTION
	SCREWED CONNECTION
	UNION
	COUPLING
	RUPTURE DISK
	REDUCER
	STRAINER
	FLOW RESTRICTOR
	FLEX HOSE
	CAM LOCK
	REMOVABLE CLEAR PIPE
	EXPANSION JOINT/SLEEVE
	HOSE CONNECTION
	PNEUMATIC QUICK CONNECT
	PLUG
	PIPE CAP
	SLIP UPDRAFT VENT CAP
	ELBOW - TURNED UP
	ELBOW - TURNED DOWN
	ELBOW - 90°
	ELBOW - 45°

VALVE ABBREVIATIONS

N.C. - NORMALLY CLOSED
N.O. - NORMALLY OPEN
MAN - MANUAL

MATERIAL SPECIFICATION:

PV - POLYVINYL CHLORIDE
GM - GALVANIZED
RC - RIGID COPPER
IR - IRON
ABS - ACRYLONITRILE BUTADIENE STYRENE
FL - FLEX

PROCESS LINE INDICATORS

	FLOW DIRECTION
	MAJOR PROCESS PIPING
	MINOR PROCESS PIPING
	WATER/AIR PIPING
	AIR PIPING
	INSTRUMENTATION CONTROLS
	PNEUMATIC LINE
	CONNECTING LINE
	CROSSOVER LINE

PROCESS LINE ABBREVIATIONS

ES - ELECTRIC SUPPLY
GS - GAS SUPPLY
HS - HYDRAULIC SUPPLY
NS - NITROGEN SUPPLY
SS - STEAM SUPPLY
W - WATER SUPPLY
V - VACUUM
VR - VAPOR REMOVAL
TF - TOTAL FLUIDS
AP - ACCESS PIPE / CONDUIT
SA - SPARGE AIR
PN - PNEUMATIC SUPPLY

	ELBOW - LONG RADIUS
	REDUCING ELBOW
	TEE REDUCING
	TEE (OUTLET UP)
	TEE (OUTLET DOWN)
	TEE

LINE DESIGNATION:

2 - VR - 01 - PV
SIZE IN PROCESS LINE MATERIAL
INCHES NUMBER SPECIFICATION

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REV	DATE	NAME
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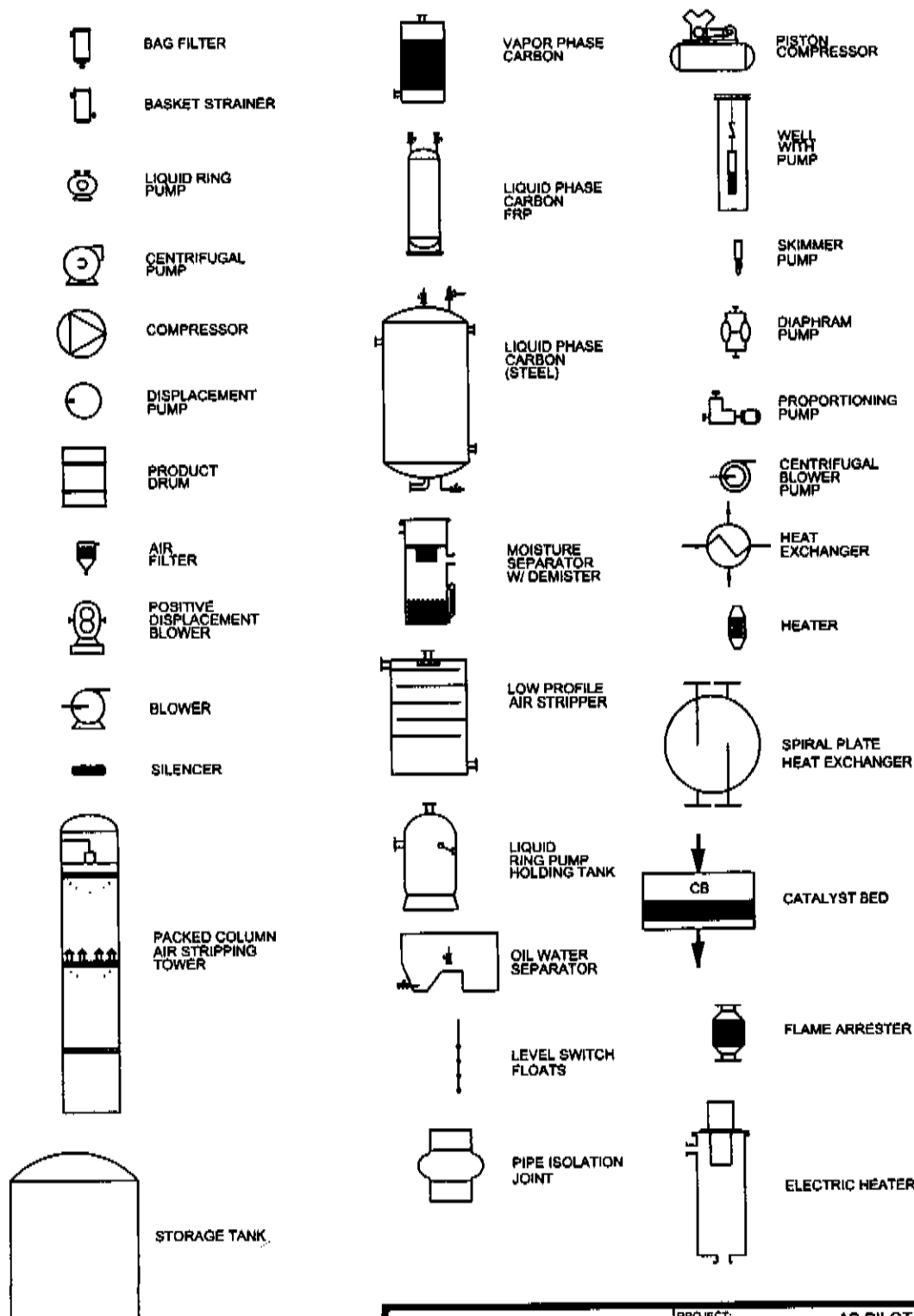
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PROJECT: AS PILOT TEST
SITE LOCATION: FORMER ANGELES CHEMICAL SITE
8620 SORENSSEN AVENUE
SANTA FE SPRINGS, CA
TITLE: SYMBOLS AND LEGEND SHEET
PIPING & PIPING COMPONENT SYMBOLS

FIGURE NO.	SHEET NO.	SHEET SIZE
5-3	2 OF 7	A

LEU 002277

EQUIPMENT SYMSBOLS



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REV	DATE	NAME
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PROJECT:

AS PILOT TEST

SITE LOCATION:

FORMER ANGELES CHEMICAL SITE
8820 SORENSEN AVENUE
SANTA FE SPRINGS, CA

TITLE:

SYMBOLS AND LEGEND SHEET
EQUIPMENT SYMBOLS

FIGURE NO.

5-4

SHEET NO.

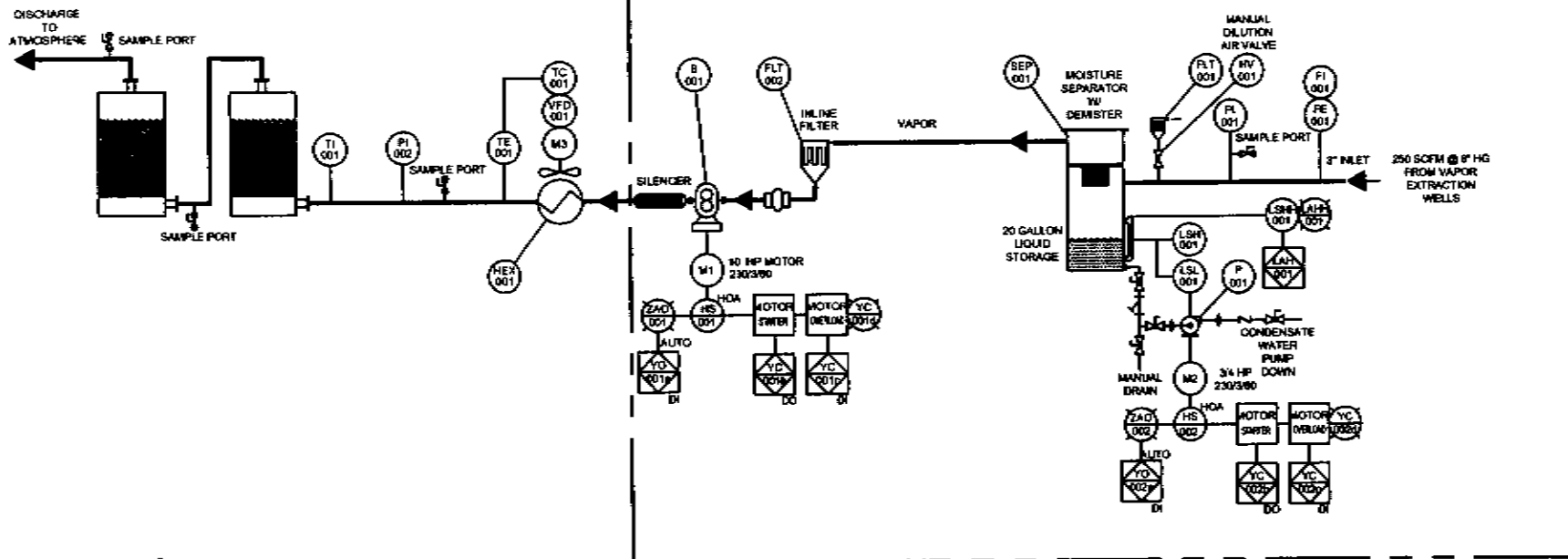
3 OF 7

SHEET
SIZE

A

SCALE:

NTS



VACUUM EXTRACTION EQUIPMENT SKID

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PROJECT:

AS PILOT TEST

SITE LOCATION:

FORMER ANGELES CHEMICAL SITE
8620 SORESENSEN AVENUE
SANTA FE SPRINGS, CA

TITLE:

VAPOR EXTRACTION EQUIPMENT P&ID

REV	DATE	NAME
0	03/20/2006	RHG

FIGURE NO.

SHEET NO.

SHEET
SIZE

SCALE:

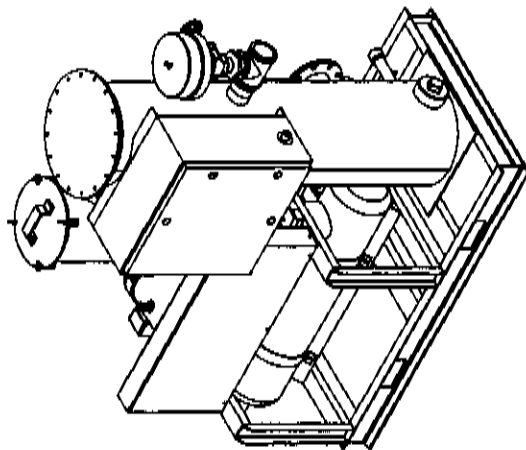
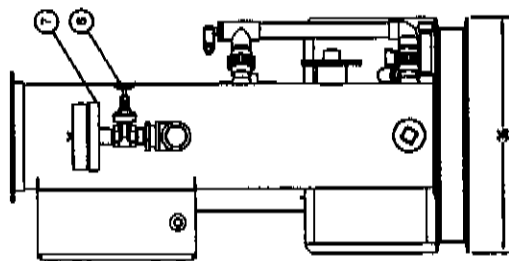
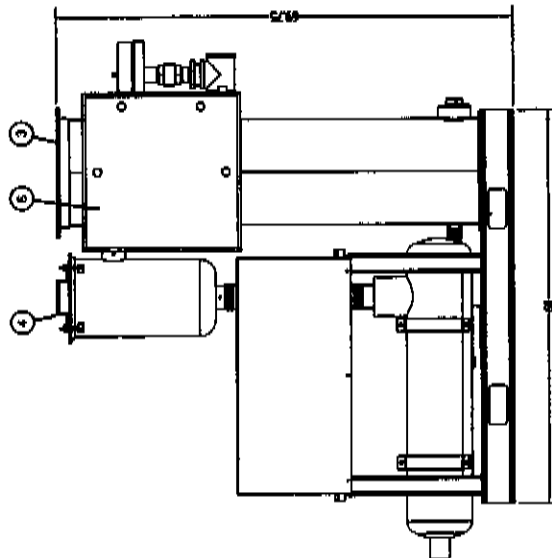
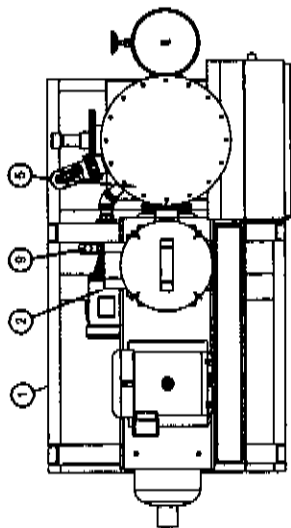
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5-5

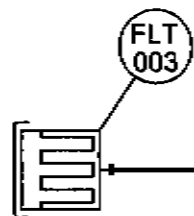
4 OF 7

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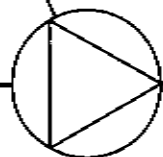
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18	03/20/2006	REVISION	WJ
19	03/20/2006	REVISION	WJ
20	03/20/2006	REVISION	WJ



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REV	DATE	NAME	
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TITLE: VAPOR EXTRACTION EQUIPMENT DRAWING		FIGURE NO.	5-6
SCALE: NTS		SHEET NO.	5 OF 7
		SHEET SIZE	A



C
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PI
003

TAH
001
TSH
001

TI
002

FLT
004



HV
002

FI
002

FE
002

TO SPARGING WELL

PORTABLE COMPRESSOR

THE LEU GROUP

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FAX: (949) 248-6785

REV	DATE	NAME
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SCALE: NTS

PROJECT: AS PILOT TEST

SITE LOCATION: FORMER ANGELES CHEMICAL SITE
8620 SORESENSEN AVENUE
SANTA FE SPRINGS, CA

TITLE: AIR SPARGING EQUIPMENT P&ID

FIGURE NO.

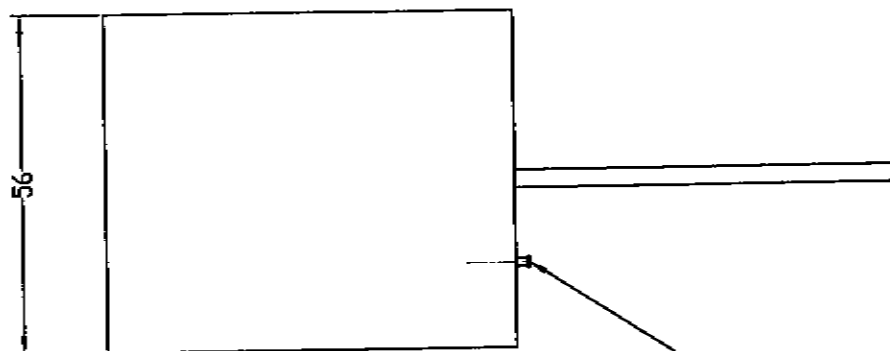
5-7

SHEET NO.

6 OF 7

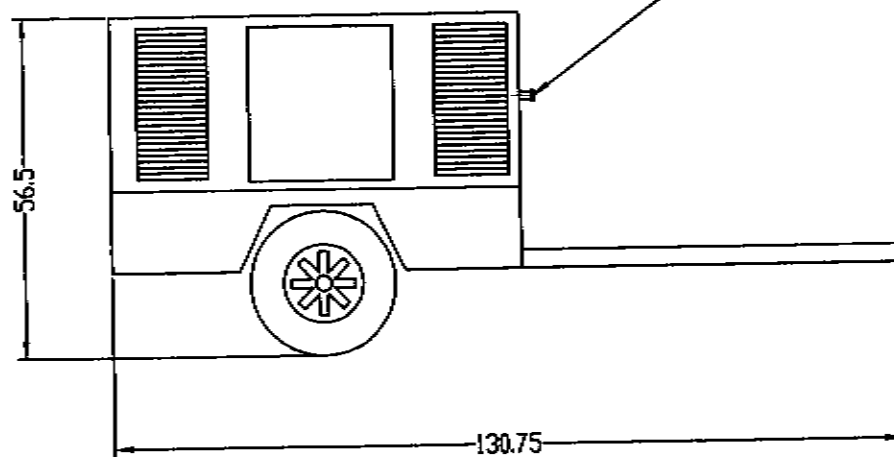
SHEET
SIZE
A

LEU 002281



TOP VIEW OF AIR COMPRESSOR

AIR COMPRESSOR DISCHARGE CONNECTION



SIDE VIEW OF AIR COMPRESSOR

THE LEU GROUP

33725 MAGELLAN ISLE
MONARCH BEACH, CA 92629
PHONE: (949) 248-5873
FAX: (949) 248-6795

REV	DATE	NAME
0	03/20/2006	RHG

SCALE:

NAME

RHG

NTS

PROJECT:

AS PILOT TEST

SITE LOCATION:

FORMER ANGELES CHEMICAL SITE
8620 SORESENSEN AVENUE
SANTA FE SPRINGS, CA

TITLE:

AIR SPARGING EQUIPMENT

FIGURE NO.

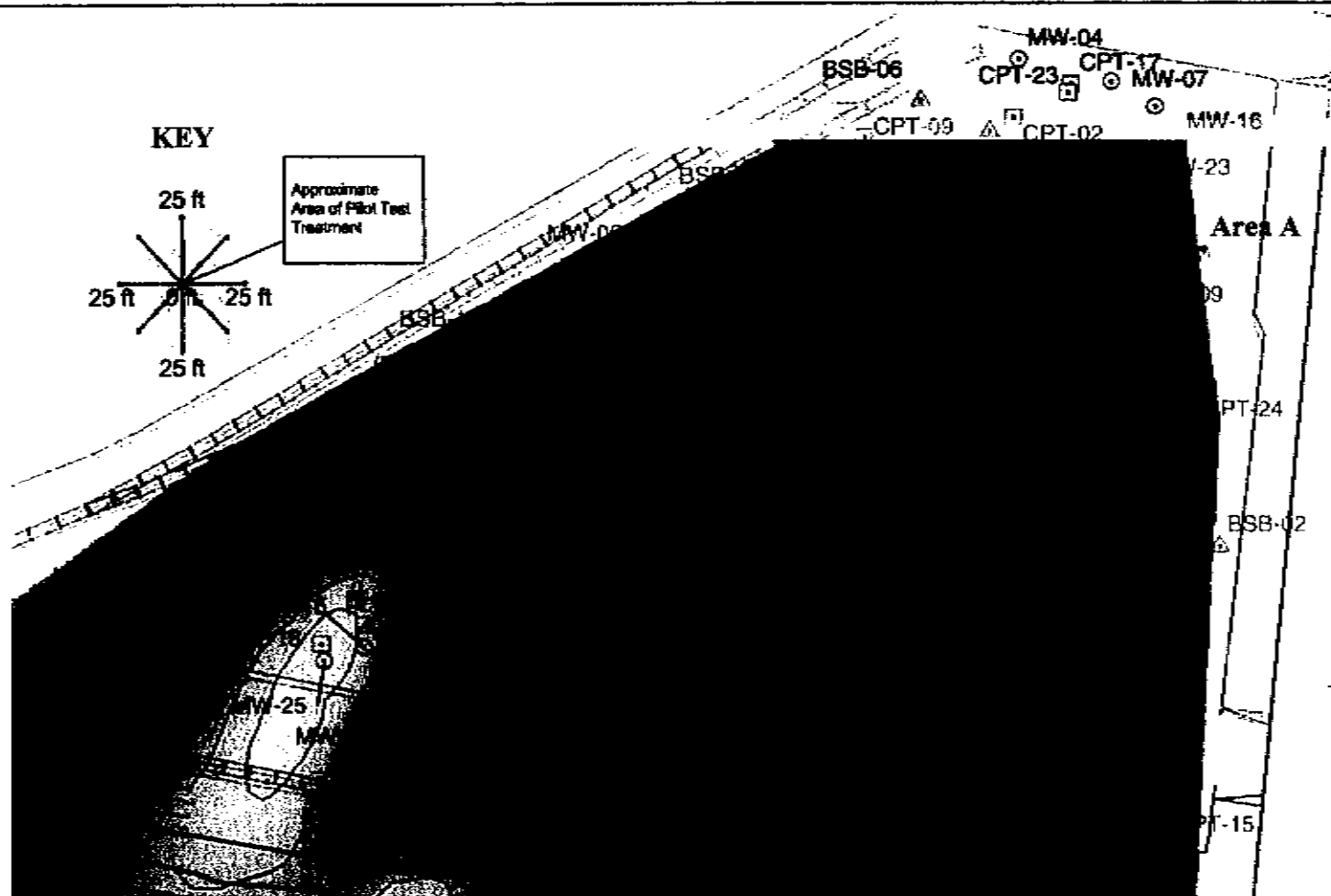
5-8

SHEET NO.

7 OF 7

SHEET
SIZE

A



AIR SPARGING PILOT TEST LOCATIONS

Figure:

6-1

FORMER ANGELES CHEMICAL SITE
8620 Sorensen Avenue,
Santa Fe Spring CA

Project: Greve AS
Pilot Test

THE LEU GROUP
Protecting Your
Quality Of Life

33725 MAGELLAN ISLE
MONARCH BEACH, CA 92629
PHONE: (949) 248-5873
FAX: (949) 248-8785

FIGURE 6-2

MULTI-LEVEL SAMPLING DEVICE CONSTRUCTION DIAGRAM

Number:

Client:

Greve Financial Services

Sheet:

Date Started:

Date Finished:

Location:

8915 Sorensen Santa Fe Springs, CA

TLGRep:

David J. Leu, Ph. D.

Drill Rig/Sampling Method:

Borehole Dia.:

Casing Dia.:

Casing Elevation
(AMSL):

2 inch Sch. 80
PVC

1/8 inch O. D.
Stainless Steel
Tube

1/8 inch Swagelock by
1/8 inch Male NPT
Connector

3/8 inch NPT Plug
(PVC Flush Mount)

100-Mesh SS Screen
"PVC Welded" to the
PVC Pipe

FIGURE 6-3

PIEZOMETER CONSTRUCTION DIAGRAM

Number:

Client:

Greve Financial Services

Sheet:

Location:

8915 Sorensen Santa Fe Springs, CA

Date Started:

Date Finished:

TLGRep:

Mark Slatten, RG/CEG

Drill Rig/Sampling Method:

Geoprobe 6600

Borehole Dia.:

3.25"

Casing Dia.:

1.50"

Casing Elevation
(AMSL):

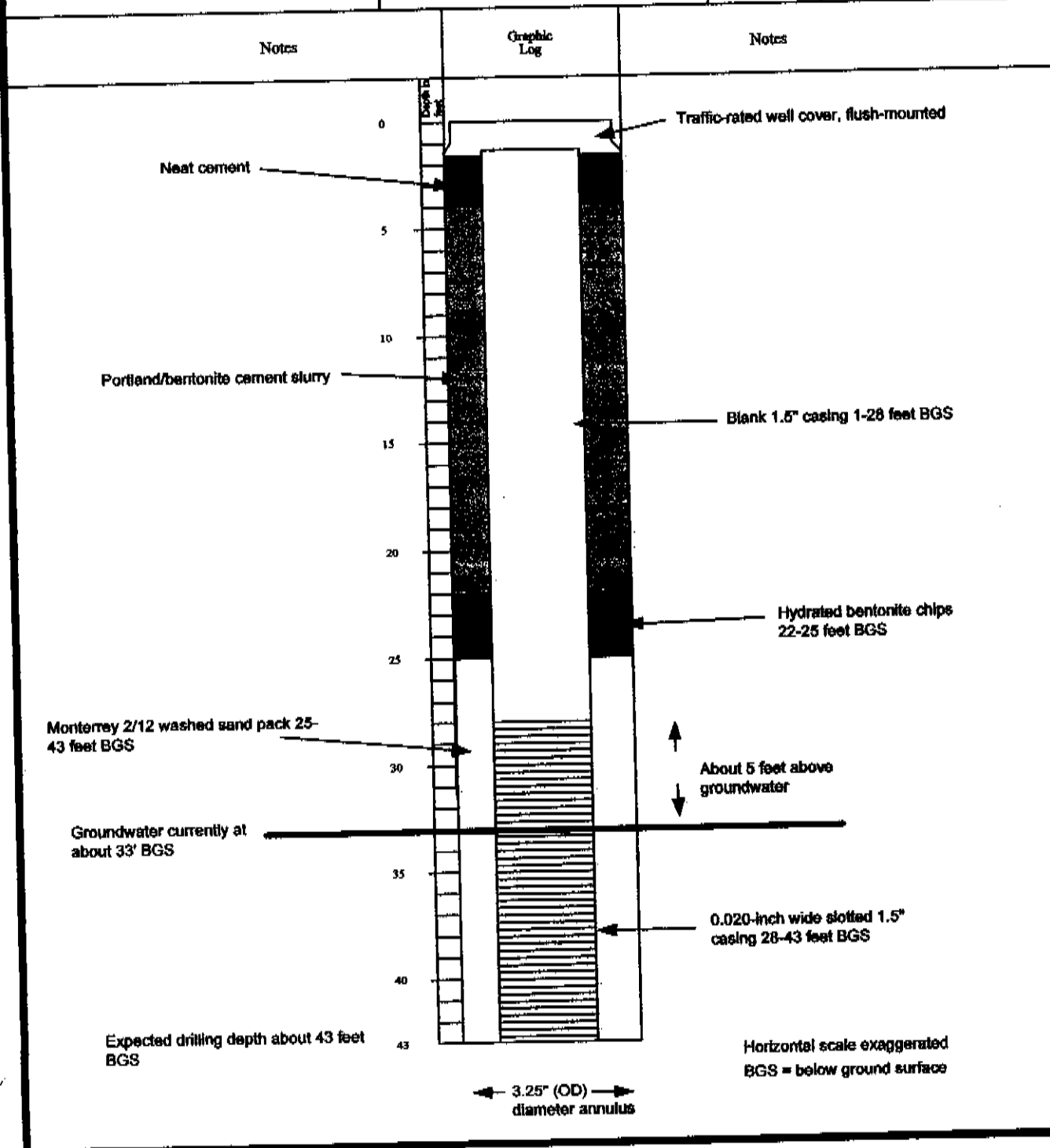


FIGURE 6-4

SVE WELL CONSTRUCTION DIAGRAM

Number:

Client:

Greve Financial Services

Sheet:

Date Started:

Date Finished:

Location:

8915 Sorensen Santa Fe Springs, CA

TLGRep:

Mark Slatten, RG/CEG

Drill Rig/Sampling Method:

Geoprobe 6600

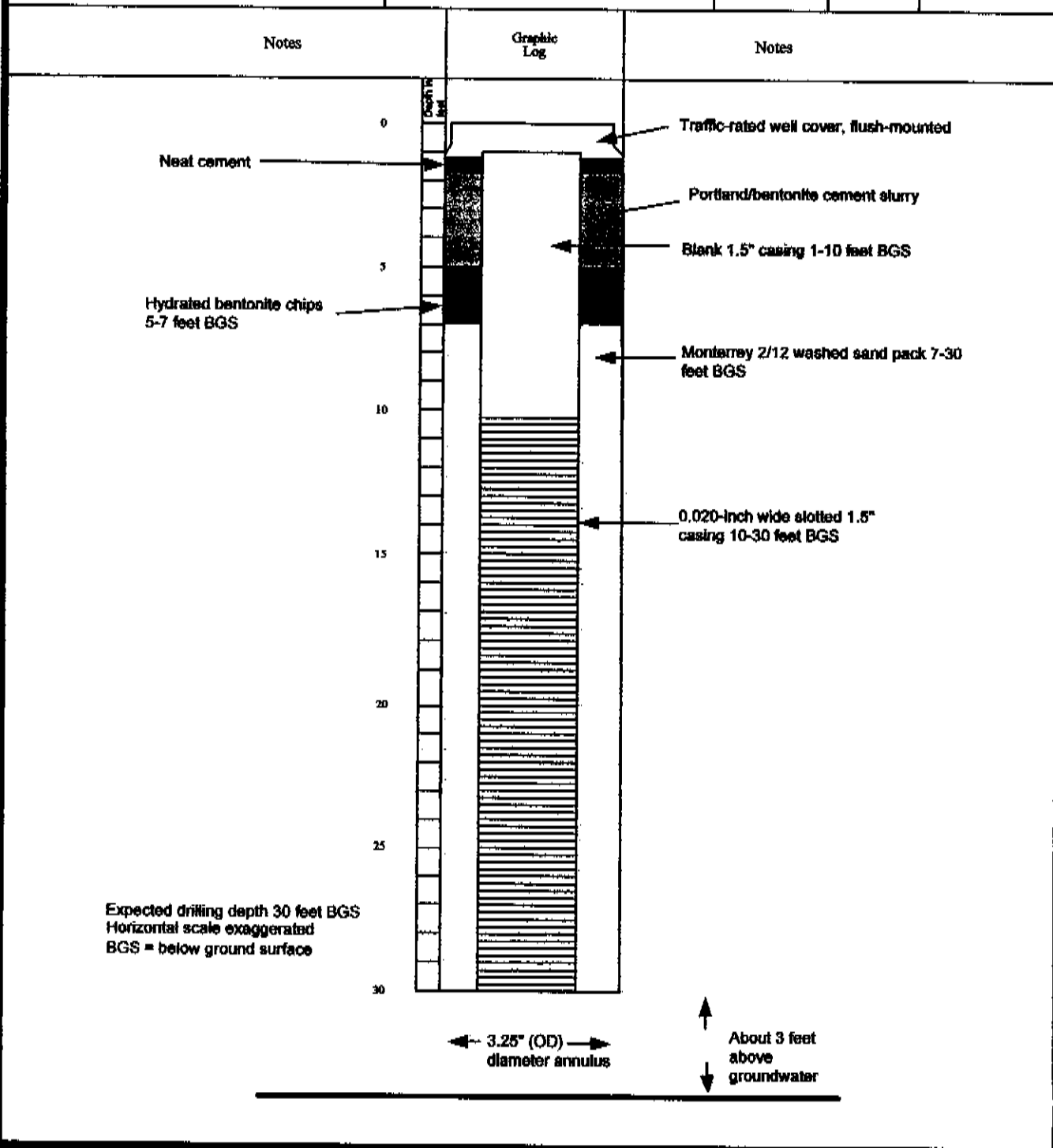
Borehole Dia.:

3.25"

Casing Dia.:

1.75"

Casing Elevation
(AMSL):



TABLES

TABLE 4-1

**DEPTH TO GROUNDWATER
AND
THICKNESS OF GROUNDWATER**

Well #	Depth To Water	Bottom	Thickness of Water
6	29.9	30.24	0.34
8	33.26	40.69	7.43
9	33.56	45.99	12.43
10	33.00	40.59	7.59
11	32.71	39.81	7.1
12	33.28	43.96	10.68
16	32.23	45.22	12.99
18	34.85	45.84	10.99
19	33.71	45.00	11.29
22	39.88	40.1	0.22
26	38.98	39.65	0.67

Based on December 2005 data.
Values in feet below ground surface.

APPENDIX A
FIGURES AND INFORMATION TAKEN FROM
SHAW (2004) And BELL (2002)



Daniel B. Stephens & Associates, Inc.

Summary of Tests Performed

Laboratory Sample Number	Initial Soil Properties ¹ (θ , ρ_d , ϕ)	Saturated Hydraulic Conductivity ²		Moisture Characteristics ³					Unsaturated Hydraulic Conductivity	Particle Size ⁴			Effective Porosity	Particle Density	TOC	1/3, 15 Bar Points and Water Holding Capacity	Atterberg Limits or Visual classification of fines
		CH	FH	HC	PP	TH	WP	RH		DS	WS	H					
MW-12 (13.5-14.5)	X		X								X	X		X	X		X
MW-12 (21-22)	X	X									X	X		X	X		**
MW-12 (31-32)	X	X									X	X		X	X		**
MW-12 (46-47)	X		X								X	X		X	X		X
MW-15 (13.5-14.5)	X		X								X	X		X	X		X
MW-15 (23.5-24.5)	X	X									X	X		X	X		**
MW-15 (28.5-29.5) ^c	X		X								X	X		X	X		X
MW-15 (38.5-39.5) ^d	X		X								X	X		X	X		X
MW-16 (13.5-14.5)	X	X									X	X		X	X		X
MW-16 (23.5-24.5)	X	X									X	X		X	X		X
MW-16 (28.5-29.5)	X	X									X	X		X	X		X
MW-16 (38.5-39.5)	X	X									X	X		X	X		X

*Atterbergs were not necessary for engineering classification

θ = Initial moisture content, ρ_d = Dry bulk density, ϕ = Calculated porosity

CH = Constant head, FH = falling head

HC = Hanging column, PP = Pressure plate, TH = Thermocouple psychrometer, WP = Water activity meter, RH = Relative humidity box

DS = Dry sieve, WS = Wet sieve, H = Hydrometer



**Summary of Initial Moisture Content, Dry Bulk Density
Wet Bulk Density and Calculated Porosity**

Sample Number	Initial Moisture Content		Dry Bulk Density (g/cm ³)	Wet Bulk Density (g/cm ³)	Calculated Porosity (%)
	Gravimetric (%, g/g)	Volumetric (%, cm ³ /cm ³)			
MW-12 (13.5-14.5)	16.3	28.5	1.74	2.03	37.1
MW-12 (21-22)	2.6	4.3	1.66	1.70	37.6
MW-12 (31-32)	3.5	4.8	1.35	1.40	49.3
MW-12 (46-47)	36.3	49.8	1.37	1.87	49.8
MW-15 (13.5-14.5)	14.4	24.6	1.71	1.96	38.2
MW-15 (23.5-24.5)	4.6	7.7	1.66	1.74	37.5
MW-15 (28.5-29.5)	26.4	40.9	1.55	1.96	44.2
MW-15 (38.5-39.5)	27.3	41.0	1.50	1.91	45.4
MW-16 (13.5-14.5)	14.6	25.0	1.71	1.96	37.8
MW-16 (23.5-24.5)	3.2	4.7	1.47	1.51	44.5
MW-16 (28.5-29.5)	20.8	31.1	1.49	1.81	45.4
MW-16 (38.5-39.5)	28.5	42.8	1.50	1.93	45.1



Summary of Saturated Hydraulic Conductivity Tests

Sample Number	K_{sat} (cm/sec)	Method of Analysis	
		Constant Head	Falling Head
MW-12 (13.5-14.5)	1.5E-06		X
MW-12 (21-22)	1.4E-01	X	
MW-12 (31-32)	5.3E-02	X	
MW-12 (46-47)	2.8E-06		X
MW-15 (13.5-14.5)	3.8E-07		X
MW-15 (23.5-24.5)	1.5E-02	X	
MW-15 (28.5-29.5)	6.0E-07		X
MW-15 (38.5-39.5)	4.8E-06		X
MW-16 (13.5-14.5)	4.1E-05	X	
MW-16 (23.5-24.5)	2.4E-02	X	
MW-16 (28.5-29.5)	1.4E-04	X	
MW-16 (38.5-39.5)	3.2E-05	X	



Summary of Particle Size Characteristics

Sample Number	d ₁₀ (mm)	d ₅₀ (mm)	d ₆₀ (mm)	C _u	C _c	Method	ASTM Classification	USDA Classification	
MW-12 (13.5-14.5)	9.5E-05	0.046	0.057	600	36	WS/H	Silt with sand	Loam	(Est)
MW-12 (21-22)	0.55	3.2	4.5	8.2	1.0	WS/H	Well-graded sand with gravel	NA	
MW-12 (31-32)	0.26	0.56	0.64	2.5	1.1	WS/H	Poorly-graded sand	Sand	
MW-12 (46-47)	0.0014	0.025	0.041	29	1.7	WS/H	Silt with sand	Silt Loam	
MW-15 (13.5-14.5)	0.00019	0.064	0.097	511	29	WS/H	Sandy silt	Sandy Loam	(Est)
MW-15 (23.5-24.5)	0.19	1.1	2.4	13	0.48	WS/H	Poorly-graded sand with gravel	NA	
MW-15 (28.5-29.5)	0.0014	0.019	0.025	18	2.1	WS/H	Silt with sand	Silt Loam	
MW-15 (38.5-39.5)	0.0010	0.014	0.020	20	2.5	WS/H	Silt	Silt Loam	(Est)
MW-16 (13.5-14.5)	3.3E-05	0.049	0.068	2061	114	WS/H	Sandy lean clay	Loam	(Est)
MW-16 (23.5-24.5)	0.079	0.57	0.73	9.2	1.7	WS/H	Well-graded sand with silt	Loamy Sand	
MW-16 (28.5-29.5)	0.00033	0.015	0.027	82	2.1	WS/H	Lean clay with sand	Silt Loam	(Est)

d₅₀ = Median particle diameter

Est = Reported values for d₁₀, C_u, C_c, and soil classification are estimates, since extrapolation was required to obtain the d₁₀ diameter

$$C_u = \frac{d_{60}}{d_{10}}$$

$$C_c = \frac{(d_{30})^2}{(d_{10})(d_{60})}$$

DS = Dry sieve

H = Hydrometer

WS = Wet sieve

LEU 002293



Daniel B. Stephens & Associates, Inc.

Summary of Particle Size Characteristics (Continued)

Sample Number	d ₁₀ (mm)	d ₅₀ (mm)	d ₆₀ (mm)	C _u	C _c	Method	ASTM Classification	USDA Classification
MW-16 (38.5-39.5)	0.0040	0.027	0.033	8.3	1.9	WS/H	Silt	Silt Loam

d₅₀ = Median particle diameter

Est = Reported values for d₁₀, C_u, C_c, and soil classification are estimates, since extrapolation was required to obtain the d₁₀ diameter

$$C_u = \frac{d_{60}}{d_{10}}$$

$$C_c = \frac{(d_{30})^2}{(d_{10})(d_{60})}$$

DS = Dry sieve

H = Hydrometer

WS = Wet sieve

LEU 002294



Daniel B. Stephens & Associates, Inc.

Summary of Particle Density Tests

Sample Number	Particle Density (g/cm ³)
MW-12 (13.5-14.5)	2.77
MW-12 (21-22)	2.65
MW-12 (31-32)	2.66
MW-12 (46-47)	2.74
MW-15 (13.5-14.5)	2.77
MW-15 (23.5-24.5)	2.66
MW-15 (28.5-29.5)	2.78
MW-15 (38.5-39.5)	2.75
MW-16 (13.5-14.5)	2.75
MW-16 (23.5-24.5)	2.64
MW-16 (28.5-29.5)	2.74
MW-16 (38.5-39.5)	2.74



Summary of Atterberg Tests

Sample Number	Liquid Limit	Plastic Limit	Plasticity Index	Classification
MW-12 (13.5-14.5)	27.4	23.2	4.2	ML
MW-12 (46-47)	32.4	26.7	5.7	ML
MW-15 (13.5-14.5)	21.4	19.2	2.2	ML
MW-15 (28.5-29.5)	---	---	---	ML
MW-15 (38.5-39.5)	35.9	---	---	ML
MW-16 (13.5-14.5)	29.5	21.6	7.9	CL
MW-16 (23.5-24.5)	---	---	---	ML
MW-16 (28.5-29.5)	37.5	23.9	13.6	CL
MW-16 (38.5-39.5)	---	---	---	ML

--- = Soil requires visual-manual classification due to non-plasticity



Daniel B. Stephens & Associates, Inc.

Summary of Fraction Organic Carbon Tests

<u>Sample Number</u>	<u>Fraction Organic Carbon (%)</u>
MW-12 (13.5-14.5)	ND
MW-12 (21-22)	ND
MW-12 (31-32)	0.14
MW-12 (46-47)	0.13
MW-15 (13.5-14.5)	0.12
MW-15 (23.5-24.5)	0.14
MW-15 (28.5-29.5)	0.13
MW-15 (38.5-39.5)	0.12
MW-16 (13.5-14.5)	0.19
MW-16 (23.5-24.5)	0.12
MW-16 (28.5-29.5)	0.18
MW-16 (38.5-39.5)	0.14

ND-Not detected at the reporting limit

Analysis provided by Hall Environmental, Albuquerque, NM.

Laboratory Tests and Methods



Daniel B. Stephens & Associates, Inc.

Tests and Methods

Dry Bulk Density:	ASTM D 4531-91
Moisture Content:	ASTM D 2216-92
Calculated Porosity	Klute, A. 1986. Porosity. Chp.18-2.1, pp. 444-445, in A. Klute (ed.), Methods of Soil Analysis, American Society of Agronomy, Madison, WI
Ksat:	
Constant Head:	ASTM D 2434-68 (93)
Falling Head:	Klute, A. and C. Dirksen. 1986. Hydraulic Conductivity and Diffusivity: Laboratory Methods. Chp. 28, pp. 200-203, in A. Klute (ed.), Methods of Soil Analysis, American Society of Agronomy, Madison, WI
Particle Size Analysis	ASTM D 422-63 (90)
Particle Density	ASTM D 854-92
Atterberg Limits	ASTM D 4318-93
Visual-Manual Estimation of Fines	ASTM D 2488-93
TOC:	Page, A. L. 1982 Chp. 19-3, pp. 570-571, in A. L. Page (ed), Methods of Soil Analysis American Society of Agronomy, Madison, WI

Raw Laboratory Data and Graphical Plots



Daniel B. Stephens & Associates, Inc.

**Summary of Initial Moisture Content, Dry Bulk Density
Wet Bulk Density and Calculated Porosity**

Sample Number	Initial Moisture Content		Dry Bulk Density (g/cm ³)	Wet Bulk Density (g/cm ³)	Calculated Porosity (%)
	Gravimetric (%, g/g)	Volumetric (%, cm ³ /cm ³)			
MW-12 (13.5-14.5)	16.3	28.5	1.74	2.03	37.1
MW-12 (21-22)	2.6	4.3	1.66	1.70	37.6
MW-12 (31-32)	3.5	4.8	1.35	1.40	49.3
MW-12 (46-47)	36.3	49.8	1.37	1.87	49.8
MW-15 (13.5-14.5)	14.4	24.6	1.71	1.96	38.2
MW-15 (23.5-24.5)	4.6	7.7	1.66	1.74	37.5
MW-15 (28.5-29.5)	26.4	40.9	1.55	1.96	44.2
MW-15 (38.5-39.5)	27.3	41.0	1.50	1.91	45.4
MW-16 (13.5-14.5)	14.6	25.0	1.71	1.96	37.8
MW-16 (23.5-24.5)	3.2	4.7	1.47	1.51	44.5
MW-16 (28.5-29.5)	20.8	31.1	1.49	1.81	45.4
MW-16 (38.5-39.5)	28.5	42.8	1.50	1.93	45.1



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (13.5-14.5)
Ring Number: NA
Depth: NA

Test Date: 28-Jan-03

Field weight* of sample (g): 88.30
Tare weight, ring (g): 22.99
Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 56.14
Sample volume (cm³): 32.23
Measured particle density: 2.77

Initial Volumetric Moisture Content (% vol): 28.5
Initial Gravimetric Moisture Content (% g/g): 16.3
Dry bulk density (g/cm³): 1.74
Wet bulk density (g/cm³): 2.03
Calculated Porosity (% vol): 37.1
Percent Saturation: 76.8

Comments:

* Weight including tares

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (21-22)
Ring Number: NA
Depth: NA
Test Date: 28-Jan-03

Field weight of sample (g):* 517.76
Tare weight, ring (g): 139.14
Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 369.03
Sample volume (cm³): 222.66
Measured particle density: 2.65

Initial Volumetric Moisture Content (% vol): 4.3
Initial Gravimetric Moisture Content (% g/g): 2.6
Dry bulk density (g/cm³): 1.66
Wet bulk density (g/cm³): 1.70
Calculated Porosity (% vol): 37.6
Percent Saturation: 11.5

Comments:

* Weight including tares

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (31-32)
Ring Number: NA
Depth: NA

Test Date: 28-Jan-03

Field weight of sample (g):* 286.02
Tare weight, ring (g): 87.14
Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 192.08
Sample volume (cm³): 142.20
Measured particle density: 2.66

Initial Volumetric Moisture Content (% vol): 4.8

Initial Gravimetric Moisture Content (% g/g): 3.5

Dry bulk density (g/cm³): 1.35

Wet bulk density (g/cm³): 1.40

Calculated Porosity (% vol): 49.3

Percent Saturation: 9.7

Comments:

* Weight including tares

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (46-47)
Ring Number: NA
Depth: NA

Test Date: 28-Jan-03

Field weight of sample (g):* 155.73
Tare weight, ring (g): 41.37
Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 83.93
Sample volume (cm³): 61.10
Measured particle density: 2.74

Initial Volumetric Moisture Content (% vol): 49.8
Initial Gravimetric Moisture Content (% g/g): 36.3
Dry bulk density (g/cm³): 1.37
Wet bulk density (g/cm³): 1.87
Calculated Porosity (% vol): 49.8
Percent Saturation: 100.0

Comments:

* Weight including tares

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental

Job Number: WR03.0011.00

Sample Number: MW-15 (13.5-14.5)

Ring Number: NA

Depth: NA

Test Date: 28-Jan-03

Field weight of sample (g): 93.76*

Tare weight, ring (g): 24.31

Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 60.73

Sample volume (cm³): 35.44

Measured particle density: 2.77

Initial Volumetric Moisture Content (% vol): 24.6

Initial Gravimetric Moisture Content (% g/g): 14.4

Dry bulk density (g/cm³): 1.71

Wet bulk density (g/cm³): 1.96

Calculated Porosity (% vol): 38.2

Percent Saturation: 64.5

Comments:

** Weight including tares*

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (23.5-24.5)
Ring Number: NA
Depth: NA

Test Date: 28-Jan-03

Field weight of sample (g):* 334.48
Tare weight, ring (g): 86.97
Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 236.53
Sample volume (cm³): 142.37
Measured particle density: 2.66

Initial Volumetric Moisture Content (% vol): 7.7

Initial Gravimetric Moisture Content (% g/g): 4.6

Dry bulk density (g/cm³): 1.66

Wet bulk density (g/cm³): 1.74

Calculated Porosity (% vol): 37.5

Percent Saturation: 20.6

Comments:

* Weight including tares

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (28.5-29.5)
Ring Number: NA
Depth: NA

Test Date: 28-Jan-03

Field weight of sample (g):* 101.28
Tare weight, ring (g): 26.66
Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 59.05
Sample volume (cm³): 38.07
Measured particle density: 2.78

Initial Volumetric Moisture Content (% vol): 40.9
Initial Gravimetric Moisture Content (% g/g): 26.4
Dry bulk density (g/cm³): 1.55
Wet bulk density (g/cm³): 1.96
Calculated Porosity (% vol): 44.2
Percent Saturation: 92.6

Comments:

* Weight including tares

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (38.5-39.5)
Ring Number: NA
Depth: NA
Test Date: 28-Jan-03

Field weight of sample (g):* 132.10
Tare weight, ring (g): 35.21
Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 76.09
Sample volume (cm³): 50.70
Measured particle density: 2.75

Initial Volumetric Moisture Content (% vol): 41.0
Initial Gravimetric Moisture Content (% g/g): 27.3
Dry bulk density (g/cm³): 1.50
Wet bulk density (g/cm³): 1.91
Calculated Porosity (% vol): 45.4
Percent Saturation: 90.4

Comments:

* Weight including tares

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (13.5-14.5)
Ring Number: NA
Depth: NA

Test Date: 28-Jan-03

Field weight of sample (g):* 268.91
Tare weight, ring (g): 61.54
Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 180.89
Sample volume (cm³): 105.86
Measured particle density: 2.75

Initial Volumetric Moisture Content (% vol): 25.0
Initial Gravimetric Moisture Content (% g/g): 14.6
Dry bulk density (g/cm³): 1.71
Wet bulk density (g/cm³): 1.96
Calculated Porosity (% vol): 37.8
Percent Saturation: 66.1

Comments:

* Weight including tares

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

*Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (23.5-24.5)
Ring Number: NA
Depth: NA*

Test Date: 28-Jan-03

Field weight of sample (g): 451.46
Tare weight, ring (g): 110.47
Tare weight, cap/plate/epoxy (g): 0.00*

*Dry weight of sample (g): 330.43
Sample volume (cm³): 225.28
Measured particle density: 2.64*

*Initial Volumetric Moisture Content (% vol): 4.7
Initial Gravimetric Moisture Content (% g/g): 3.2
Dry bulk density (g/cm³): 1.47
Wet bulk density (g/cm³): 1.51
Calculated Porosity (% vol): 44.5
Percent Saturation: 10.5*

Comments:

* Weight including tares

*Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd*



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (28.5-29.5)
Ring Number: NA
Depth: NA

Test Date: 28-Jan-03

Field weight of sample (g):* 207.12
Tare weight, ring (g): 50.09
Tare weight, cap/plate/epoxy (g): 0.00

Dry weight of sample (g): 129.98
Sample volume (cm³): 86.99
Measured particle density: 2.74

Initial Volumetric Moisture Content (% vol): 31.1
Initial Gravimetric Moisture Content (% g/g): 20.8
Dry bulk density (g/cm³): 1.49
Wet bulk density (g/cm³): 1.81
Calculated Porosity (% vol): 45.4
Percent Saturation: 68.5

Comments:

* Weight including tares

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Data for Initial Moisture Content,
Bulk Density, Porosity, and Percent Saturation**

*Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (38.5-39.5)
Ring Number: NA
Depth: NA*

Test Date: 28-Jan-03

Field weight of sample (g): 221.87
Tare weight, ring (g): 49.69
Tare weight, cap/plate/epoxy (g): 0.00*

*Dry weight of sample (g): 133.99
Sample volume (cm³): 89.13
Measured particle density: 2.74*

*Initial Volumetric Moisture Content (% vol): 42.8
Initial Gravimetric Moisture Content (% g/g): 28.5
Dry bulk density (g/cm³): 1.50
Wet bulk density (g/cm³): 1.93
Calculated Porosity (% vol): 45.1
Percent Saturation: 95.1*

Comments:

** Weight including tares*

*Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd*



Summary of Saturated Hydraulic Conductivity Tests

Sample Number	K_{sat} (cm/sec)	Method of Analysis	
		Constant Head	Falling Head
MW-12 (13.5-14.5)	1.5E-06		X
MW-12 (21-22)	1.4E-01	X	
MW-12 (31-32)	5.3E-02	X	
MW-12 (46-47)	2.8E-06		X
MW-15 (13.5-14.5)	3.8E-07		X
MW-15 (23.5-24.5)	1.5E-02	X	
MW-15 (28.5-29.5)	6.0E-07		X
MW-15 (38.5-39.5)	4.8E-06		X
MW-16 (13.5-14.5)	4.1E-05	X	
MW-16 (23.5-24.5)	2.4E-02	X	
MW-16 (28.5-29.5)	1.4E-04	X	
MW-16 (38.5-39.5)	3.2E-05	X	



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Falling Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-12 (13.5-14.5)
Ring number: NA
Depth: NA

Type of water used: TAP
Backpressure (psi): 0.0
Offset (cm): 1.7
Sample length (cm): 3.10
Sample x-sectional area (cm²): 10.38
Reservoir x-sectional area (cm²): 0.70

Date	Time	Temp (°C)	Reservoir head (cm)	Corrected head (cm)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:							
29-Jan-03	14:59:10	20.0	90.5	88.8	61964	1.4E-06	1.5E-06
30-Jan-03	08:11:54	18.0	59.7	58.0			
Test # 2:							
30-Jan-03	08:11:54	18.0	59.7	58.0	8847	1.5E-06	1.6E-06
30-Jan-03	10:39:21	18.0	56.0	54.3			
Test # 3:							
30-Jan-03	10:39:21	18.0	56.0	54.3	13598	1.5E-06	1.5E-06
30-Jan-03	14:25:59	20.0	51.1	49.4			

Average Ksat (cm/sec): 1.5E-06

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Constant Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-12 (21-22)
Ring number: NA
Depth: NA

Type of water used: TAP
Collection vessel tare (g): 4.62
Sample length (cm): 7.60
Sample diameter (cm): 6.11
Sample x-sectional area (cm²): 29.30

Date	Time	Temp (°C)	Head (cm)	Q + Tare (g)	Q (cm ³)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:								
29-Jan-03	12:58:40	20.0	1.2	27.7	23.1	36	1.4E-01	1.4E-01
29-Jan-03	12:59:16							
Test # 2:								
29-Jan-03	15:56:27	20.0	0.3	10.3	5.7	37	1.3E-01	1.3E-01
29-Jan-03	15:57:04							
Test # 3:								
30-Jan-03	07:54:13	18.0	0.3	18.1	13.4	78	1.5E-01	1.5E-01
30-Jan-03	07:55:31							

Average Ksat (cm/sec): 1.4E-01

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Constant Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-12 (31-32)
Ring number: NA
Depth: NA

Type of water used: TAP
Collection vessel tare (g): 11.93
Sample length (cm): 7.55
Sample diameter (cm): 4.90
Sample x-sectional area (cm²): 18.83

Date	Time	Temp (°C)	Head (cm)	Q + Tare (g)	Q (cm ³)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:								
29-Jan-03	12:58:05	20.0	2.1	38.8	26.9	95	5.4E-02	5.4E-02
29-Jan-03	12:59:40							
Test # 2:								
29-Jan-03	15:55:58	20.0	2.1	23.8	11.8	38	5.9E-02	5.9E-02
29-Jan-03	15:56:36							
Test # 3:								
30-Jan-03	07:54:06	18.0	2.1	30.0	18.1	77	4.5E-02	4.7E-02
30-Jan-03	07:55:23							

Average Ksat (cm/sec): 5.3E-02

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002317



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Falling Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-12 (46-47)
Ring number: NA
Depth: NA

Type of water used: TAP
Backpressure (psi): 0.0
Offset (cm): 3.6
Sample length (cm): 5.81
Sample x-sectional area (cm²): 10.51
Reservoir x-sectional area (cm²): 0.70

Date	Time	Temp (°C)	Reservoir head (cm)	Corrected head (cm)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:							
30-Jan-03	10:37:03	18.0	100.6	97.0	13590	3.0E-06	2.9E-06
30-Jan-03	14:23:33	22.0	91.1	87.5			
Test # 2:							
30-Jan-03	14:23:33	22.0	91.1	87.5	73740	2.8E-06	2.7E-06
31-Jan-03	10:52:33	20.0	55.1	51.5			
Test # 3:							
31-Jan-03	10:52:33	20.0	55.1	51.5	16931	2.7E-06	2.7E-06
31-Jan-03	15:34:44	22.0	49.3	45.7			

Average Ksat (cm/sec): 2.8E-06

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Falling Head Method**

Job name: Shaw Environmental Type of water used: TAP
Job number: WR03.0011.00 Backpressure (psi): 0.0
Sample number: MW-15 (13.5-14.5) Offset (cm): 2.4
Ring number: NA Sample length (cm): 3.36
Depth: NA Sample x-sectional area (cm²): 10.54
Reservoir x-sectional area (cm²): 0.70

Date	Time	Temp (°C)	Reservoir head (cm)	Corrected head (cm)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:							
30-Jan-03	10:41:12	18.0	111.3	108.9	87174	3.8E-07	3.9E-07
31-Jan-03	10:54:06	20.0	96.2	93.8			
Test # 2:							
31-Jan-03	10:54:06	20.0	96.2	93.8	16891	3.9E-07	3.8E-07
31-Jan-03	15:35:37	22.0	93.5	91.1			
Test # 3:							
31-Jan-03	15:35:37	22.0	93.5	91.1	63592	3.7E-07	3.7E-07
01-Feb-03	09:15:29	19.5	84.3	81.9			

Average Ksat (cm/sec): 3.8E-07

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Constant Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-15 (23.5-24.5)
Ring number: NA
Depth: NA

Type of water used: TAP
Collection vessel tare (g): 11.81
Sample length (cm): 7.56
Sample diameter (cm): 4.90
Sample x-sectional area (cm²): 18.83

Date	Time	Temp (°C)	Head (cm)	Q + Tare (g)	Q (cm ³)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:								
29-Jan-03	13:02:14	20.0	8.5	25.8	14.0	51	1.3E-02	1.3E-02
29-Jan-03	13:03:05							
Test # 2:								
29-Jan-03	15:58:08	20.0	8.5	33.9	22.1	70	1.5E-02	1.5E-02
29-Jan-03	15:59:18							
Test # 3:								
30-Jan-03	07:54:33	18.0	8.5	43.7	31.9	87	1.7E-02	1.8E-02
30-Jan-03	07:56:00							

Average Ksat (cm/sec): 1.5E-02

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Falling Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-15 (28.5-29.5)
Ring number: NA
Depth: NA
Type of water used: TAP
Backpressure (psi): 0.0
Offset (cm): 1.7
Sample length (cm): 3.67
Sample x-sectional area (cm²): 10.38
Reservoir x-sectional area (cm²): 0.70

Date	Time	Temp (°C)	Reservoir head (cm)	Corrected head (cm)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:							
30-Jan-03	08:11:02	18.0	52.1	50.4	8817	6.5E-07	6.7E-07
30-Jan-03	10:37:59	18.0	50.9	49.2			
Test # 2:							
30-Jan-03	10:37:59	18.0	50.9	49.2	13552	6.0E-07	6.0E-07
30-Jan-03	14:23:51	22.0	49.3	47.6			
Test # 3:							
30-Jan-03	14:23:51	22.0	49.3	47.6	73737	5.5E-07	5.3E-07
31-Jan-03	10:52:48	20.0	42.2	40.5			

Average Ksat (cm/sec): 6.0E-07

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity Falling Head Method

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-15 (38.5-39.5)
Ring number: NA
Depth: NA

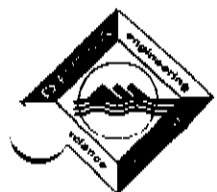
Type of water used: TAP
Backpressure (psi): 0.0
Offset (cm): 2.6
Sample length (cm): 4.85
Sample x-sectional area (cm²): 10.46
Reservoir x-sectional area (cm²): 0.70

Date	Time	Temp (°C)	Reservoir head (cm)	Corrected head (cm)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:							
29-Jan-03	14:47:40	20.0	58.6	56.0	62614	4.5E-06	4.6E-06
30-Jan-03	08:11:14	18.0	26.2	23.6			
Test # 2:							
30-Jan-03	08:11:14	18.0	26.2	23.6	8823	4.8E-06	5.0E-06
30-Jan-03	10:38:17	18.0	23.3	20.7			
Test # 3:							
30-Jan-03	10:38:17	18.0	23.3	20.7	13551	4.8E-06	4.8E-06
30-Jan-03	14:24:08	22.0	19.5	16.9			

Average Ksat (cm/sec): 4.8E-06

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Constant Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-16 (13.5-14.5)
Ring number: NA
Depth: NA

Type of water used: TAP
Collection vessel tare (g): 11.81
Sample length (cm): 5.61
Sample diameter (cm): 4.90
Sample x-sectional area (cm²): 18.88

Date	Time	Temp (°C)	Head (cm)	Q + Tare (g)	Q (cm ³)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:								
30-Jan-03	07:52:25	18.0	8.8	12.5	0.7	658	3.7E-05	3.8E-05
30-Jan-03	08:03:23							
Test # 2:								
30-Jan-03	14:18:49	22.0	8.8	12.2	0.4	297	4.2E-05	4.0E-05
30-Jan-03	14:23:48							
Test # 3:								
31-Jan-03	10:47:22	20.0	8.8	12.6	0.8	587	4.3E-05	4.3E-05
31-Jan-03	10:57:09							

Average Ksat (cm/sec): 4.1E-05

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002323



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Constant Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-16 (23.5-24.5)
Ring number: NA
Depth: NA

Type of water used: TAP
Collection vessel tare (g): 4.76
Sample length (cm): 7.61
Sample diameter (cm): 6.14
Sample x-sectional area (cm²): 29.60

Date	Time	Temp (°C)	Head (cm)	Q + Tare (g)	Q (cm ³)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:								
29-Jan-03	13:01:09	20.0	5.2	15.2	10.5	23	2.3E-02	2.2E-02
29-Jan-03	13:01:32							
Test # 2:								
29-Jan-03	15:57:32	20.0	5.2	24.1	19.3	44	2.2E-02	2.2E-02
29-Jan-03	15:58:16							
Test # 3:								
30-Jan-03	07:54:24	18.0	0.8	14.9	10.1	126	2.6E-02	2.7E-02
30-Jan-03	07:56:30							

Average Ksat (cm/sec): 2.4E-02

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002324



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Constant Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-16 (28.5-29.5)
Ring number: NA
Depth: NA

Type of water used: TAP
Collection vessel tare (g): 6.60
Sample length (cm): 4.60
Sample diameter (cm): 4.91
Sample x-sectional area (cm²): 18.93

Date	Time	Temp (°C)	Head (cm)	Q + Tare (g)	Q (cm ³)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:								
29-Jan-03	13:02:36	20.0	12.2	12.6	6.0	906	1.3E-04	1.3E-04
29-Jan-03	13:17:42							
Test # 2:								
29-Jan-03	15:59:08	20.0	12.2	13.4	6.8	1023	1.3E-04	1.3E-04
29-Jan-03	16:16:11							
Test # 3:								
30-Jan-03	07:56:47	18.0	12.2	9.8	3.2	424	1.5E-04	1.6E-04
30-Jan-03	08:03:51							
Average Ksat (cm/sec):								1.4E-04

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

**Saturated Hydraulic Conductivity
Constant Head Method**

Job name: Shaw Environmental
Job number: WR03.0011.00
Sample number: MW-16 (38.5-39.5)
Ring number: NA
Depth: NA

Type of water used: TAP
Collection vessel tare (g): 11.81
Sample length (cm): 4.68
Sample diameter (cm): 4.93
Sample x-sectional area (cm²): 19.06

Date	Time	Temp (°C)	Head (cm)	Q + Tare (g)	Q (cm ³)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:								
31-Jan-03	11:56:56	20.0	75.0	13.5	1.7	174	3.2E-05	3.2E-05
31-Jan-03	11:59:50							
Test # 2:								
31-Jan-03	15:30:30	22.0	71.4	13.7	1.8	200	3.2E-05	3.0E-05
31-Jan-03	15:33:50							
Test # 3:								
01-Feb-03	09:11:12	19.5	71.4	13.7	1.9	199	3.2E-05	3.3E-05
01-Feb-03	09:14:31							

Average Ksat (cm/sec): 3.2E-05

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002326



Daniel B. Stephens & Associates, Inc.

Summary of Particle Size Characteristics

Sample Number	d ₁₀ (mm)	d ₅₀ (mm)	d ₆₀ (mm)	C _u	C _c	Method	ASTM Classification	USDA Classification	
MW-12 (13.5-14.5)	9.5E-05	0.046	0.057	600	36	WS/H	Silt with sand	Loam	(Est)
MW-12 (21-22)	0.55	3.2	4.5	8.2	1.0	WS/H	Well-graded sand with gravel	NA	
MW-12 (31-32)	0.26	0.56	0.64	2.5	1.1	WS/H	Poorly-graded sand	Sand	
MW-12 (46-47)	0.0014	0.025	0.041	29	1.7	WS/H	Silt with sand	Silt Loam	
MW-15 (13.5-14.5)	0.00019	0.064	0.097	511	29	WS/H	Sandy silt	Sandy Loam	(Est)
MW-15 (23.5-24.5)	0.19	1.1	2.4	13	0.48	WS/H	Poorly-graded sand with gravel	NA	
MW-15 (28.5-29.5)	0.0014	0.019	0.025	18	2.1	WS/H	Silt with sand	Silt Loam	
MW-15 (38.5-39.5)	0.0010	0.014	0.020	20	2.5	WS/H	Silt	Silt Loam	(Est)
MW-16 (13.5-14.5)	3.3E-05	0.049	0.068	2061	114	WS/H	Sandy lean clay	Loam	(Est)
MW-16 (23.5-24.5)	0.079	0.57	0.73	9.2	1.7	WS/H	Well-graded sand with silt	Loamy Sand	
MW-16 (28.5-29.5)	0.00033	0.015	0.027	82	2.1	WS/H	Lean clay with sand	Silt Loam	(Est)

d₅₀ = Median particle diameter

Est = Reported values for d₁₀, C_u, C_c, and soil classification are estimates, since extrapolation was required to obtain the d₁₀ diameter

$$C_u = \frac{d_{60}}{d_{10}}$$

$$C_c = \frac{(d_{30})^2}{(d_{10})(d_{60})}$$

DS = Dry sieve

H = Hydrometer

WS = Wet sieve

LEU 002327



Daniel B. Stephens & Associates, Inc.

Summary of Particle Size Characteristics (Continued)

Sample Number	d_{10} (mm)	d_{50} (mm)	d_{60} (mm)	C_u	C_c	Method	ASTM Classification	USDA Classification
MW-16 (38.5-39.5)	0.0040	0.027	0.033	8.3	1.9	WS/H	Silt	Silt Loam

d_{50} = Median particle diameter

Est = Reported values for d_{10} , C_u , C_c , and soil classification are estimates, since extrapolation was required to obtain the d_{10} diameter

$$C_u = \frac{d_{60}}{d_{10}}$$

$$C_c = \frac{(d_{30})^2}{(d_{10})(d_{60})}$$

DS = Dry sieve

H = Hydrometer

WS = Wet sieve

LEU 002328



Daniel B. Stephens & Associates, Inc.

**Particle Size Analysis
Wet Sieve Data (#10 Split)**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (13.5-14.5)
Ring Number: NA
Depth: NA

Initial Dry Weight of Sample (g): 1333.02
Weight Passing #10 (g): 1332.68
Weight Retained #10 (g): 0.34
Weight of Hydrometer Sample (g): 50.15
Calculated Weight of Sieve Sample (g): 50.16

Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	1333.02	100.00
	1.5"	38.1	0.00	0.00	1333.02	100.00
	3/4"	19.0	0.00	0.00	1333.02	100.00
	3/8"	9.5	0.00	0.00	1333.02	100.00
	4	4.75	0.00	0.00	1333.02	100.00
	10	2.00	0.34	0.34	1332.68	99.97
-10	(Based on calculated sieve wt.)					
	20	0.85	0.19	0.20	49.96	99.60
	40	0.425	1.17	1.37	48.79	97.26
	60	0.250	1.36	2.73	47.43	94.55
	140	0.106	5.81	8.54	41.62	82.97
	200	0.075	5.47	14.01	36.15	72.07
	dry pan		2.88	16.89	33.27	
	wet pan			33.27	0.00	

d_{10} (mm): 9.5E-05

d_{50} (mm): 0.046

d_{16} (mm): 0.0024

d_{80} (mm): 0.057

d_{30} (mm): 0.014

d_{84} (mm): 0.11

Median Particle Diameter — d_{50} (mm): 0.046

Uniformity Coefficient, C_u — $[d_{60}/d_{10}]$ (mm): 600

Coefficient of Curvature, C_c — $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 36

Mean Particle Diameter — $[(d_{16} + d_{50} + d_{84})/3]$ (mm): 0.053

Note: Reported values for d_{10} , C_u , C_c , and soil classification are estimates, since extrapolation was required to obtain the d_{10} diameter

Classification of fines: ML

ASTM Soil Classification: Silt with sand

USDA Soil Classification: Loam

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: D. O'Dowd

LEU 002329



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Hydrometer Data

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (13.5-14.5)
Ring Number: NA
Depth: NA

Type of Water Used: DISTILLED
Reaction with H_2O_2 : Moderate
Dispersant: $(NaPO_3)_6$
Measured particle density: 2.77

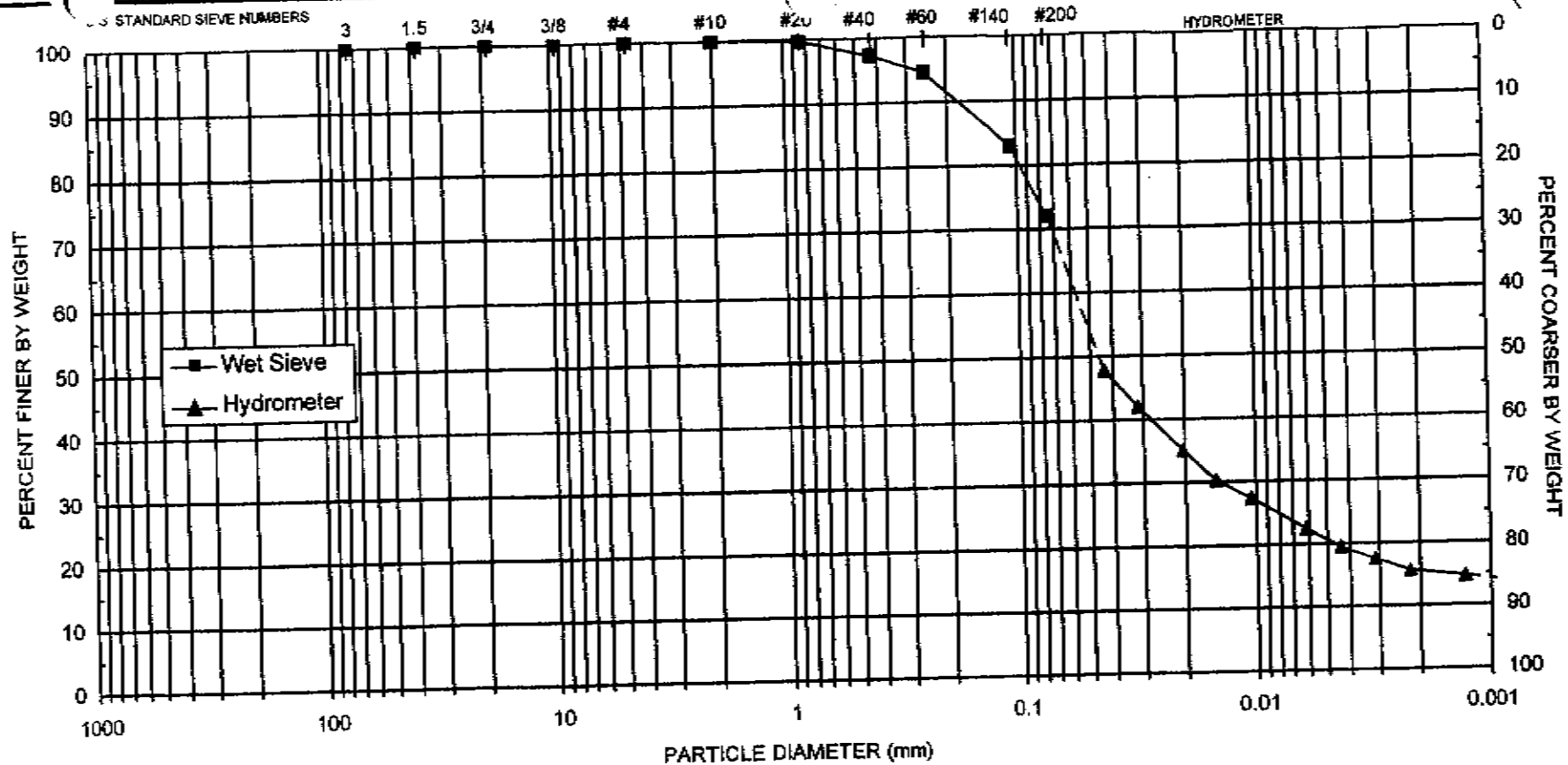
Test Date: 30-Jan-03
Start Time: 8:18

Initial Wt. (g): 50.15
Total Sample Wt. (g): 1333.02
Wt. Passing #10 (g): 1332.68

Date	Time (min)	Temp (°C)	R (g/L)	R_L (g/L)	R_{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
6-Feb-03	1	21.0	30.5	6.0	24.5	11.3	0.04371	47.9	47.9
	2	21.0	27.5	6.0	21.5	11.8	0.03157	42.0	42.0
	5	21.0	24.0	6.0	18.0	12.4	0.02045	35.2	35.2
	10	21.0	21.5	6.0	15.5	12.8	0.01470	30.3	30.3
	20	21.0	20.0	6.0	14.0	13.0	0.01049	27.4	27.4
	60	21.0	17.5	6.0	11.5	13.4	0.00615	22.5	22.5
	120	21.0	16.0	6.0	10.0	13.7	0.00439	19.5	19.5
	240	21.0	15.0	6.0	9.0	13.8	0.00312	17.6	17.6
	480	21.0	14.0	6.0	8.0	14.0	0.00222	15.6	15.6
	1440	21.0	13.5	6.0	7.5	14.1	0.00129	14.7	14.7
7-Feb-03	1440	21.0	13.5	6.0	7.5	14.1	0.00129	14.7	14.7

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd





Daniel B. Stephens & Associates, Inc.

Particle Size Analysis
Wet Sieve Data (#10 Split)

Job Name: Shaw Environmental Initial Dry Weight of Sample (g): 1326.96
Job Number: WR03.0011.00 Weight Passing #10 (g): 471.51
Sample Number: MW-12 (21-22) Weight Retained #10 (g): 855.45
Ring Number: NA Weight of Hydrometer Sample (g): 50.09
Depth: NA Calculated Weight of Sieve Sample (g): 140.97
Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	1326.96	100.00
	1.5"	38.1	0.00	0.00	1326.96	100.00
	3/4"	19.0	69.54	69.54	1257.42	94.76
	3/8"	9.5	156.80	226.34	1100.62	82.94
	4	4.75	278.80	505.14	821.82	61.93
	10	2.00	350.31	855.45	471.51	35.53
-10	(Based on calculated sieve wt.)					
	20	0.85	27.57	118.45	22.52	15.98
	40	0.425	13.56	132.01	8.96	6.36
	60	0.250	3.86	135.87	5.10	3.62
	140	0.106	2.28	138.15	2.82	2.00
	200	0.075	0.58	138.73	2.24	1.59
	dry pan		0.10	138.83	2.14	
	wet pan			2.14	0.00	

d_{10} (mm): 0.55 d_{50} (mm): 3.2
 d_{16} (mm): 0.85 d_{60} (mm): 4.5
 d_{30} (mm): 1.6 d_{84} (mm): 10

Median Particle Diameter - d_{50} (mm): 3.2
Uniformity Coefficient, C_u - $[(d_{60}/d_{10})]$ (mm): 8.2
Coefficient of Curvature, C_c - $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 1.0
Mean Particle Diameter - $[(d_{16} + d_{50} + d_{84})/3]$ (mm): 4.7

ASTM Soil Classification: Well-graded sand with gravel
USDA Soil Classification: NA

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Hydrometer Data

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (21-22)
Ring Number: NA
Depth: NA

Test Date: 31-Jan-03
Start Time: 8:36

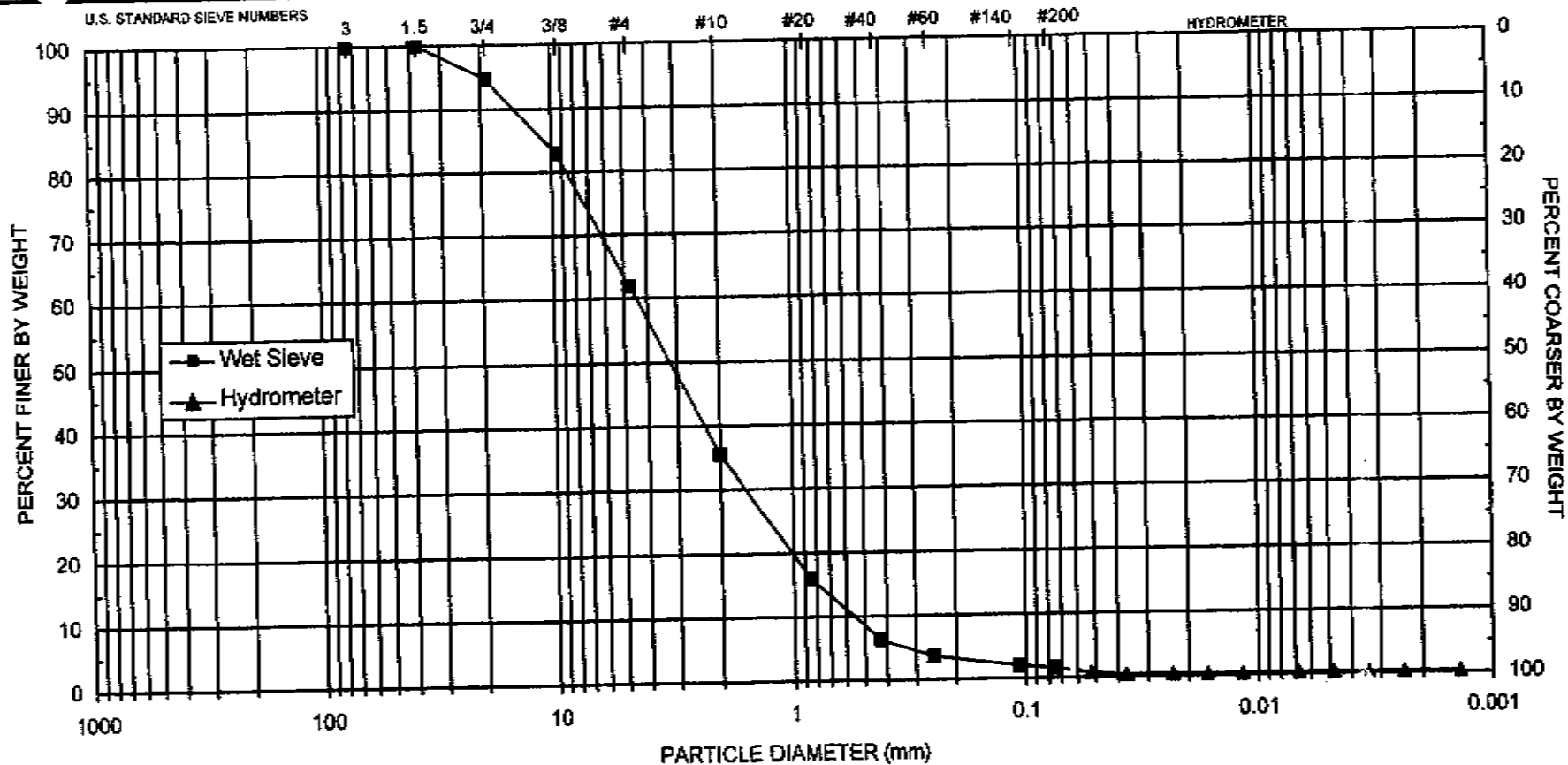
Type of Water Used: DISTILLED
Reaction with H_2O_2 : None
Dispersant: $(NaPO_3)_6$
Measured particle density: 2.65

Initial Wt. (g): 50.09
Total Sample Wt. (g): 1326.96
Wt. Passing #10 (g): 471.51

Date	Time (min)	Temp (°C)	R (g/L)	R _L (g/L)	R _{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
4-Feb-03	1	21.0	7.5	6.5	1.0	15.1	0.05218	2.0	0.7
	2	21.0	7.0	6.5	0.5	15.2	0.03699	1.0	0.4
	5	21.0	7.0	6.5	0.5	15.2	0.02340	1.0	0.4
	10	21.0	7.0	6.5	0.5	15.2	0.01654	1.0	0.4
	20	21.0	7.0	6.5	0.5	15.2	0.01170	1.0	0.4
	60	21.0	7.0	6.5	0.5	15.2	0.00675	1.0	0.4
	120	21.0	6.5	6.0	0.5	15.2	0.00479	1.0	0.4
	240	21.0	6.5	6.0	0.5	15.2	0.00339	1.0	0.4
	480	21.0	6.5	6.0	0.5	15.2	0.00239	1.0	0.4
5-Feb-03	1440	21.0	6.4	6.0	0.4	15.3	0.00138	0.8	0.3

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



UNIFIED	COBBLES	GRAVEL		SAND			SILT OR CLAY			
		Coarse	Fine	Coarse	Medium	Fine				
USDA	COBBLES	GRAVEL		SAND					SILT	CLAY
				Very coarse	Coarse	Medium	Fine	Very fine		

$d_{10} = 0.55$
 $d_{30} = 1.6$
 $d_{50} = 3.2$
 $d_{60} = 4.5$
 $C_u = 8.2$
 $C_c = 1.0$

SAMPLE NUMBER

DEPTH

ASTM CLASSIFICATION

USDA CLASSIFICATION

MW-12 (21-22)

NA

Well-graded sand with gravel

NA



Daniel B. Stephens & Associates, Inc.

LEU 002334



Daniel B. Stephens & Associates, Inc.

**Particle Size Analysis
Wet Sieve Data (#10 Split)**

Job Name: Shaw Environmental Initial Dry Weight of Sample (g): 1149.22
Job Number: WR03.0011.00 Weight Passing #10 (g): 1113.40
Sample Number: MW-12 (31-32) Weight Retained #10 (g): 35.82
Ring Number: NA Weight of Hydrometer Sample (g): 50.13
Depth: NA Calculated Weight of Sieve Sample (g): 51.74
Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	1149.22	100.00
	1.5"	38.1	0.00	0.00	1149.22	100.00
	3/4"	19.0	0.00	0.00	1149.22	100.00
	3/8"	9.5	1.92	1.92	1147.30	99.83
	4	4.75	5.79	7.71	1141.51	99.33
	10	2.00	28.11	35.82	1113.40	96.88
-10	(Based on calculated sieve wt.)					
	20	0.85	8.21	9.82	41.92	81.02
	40	0.425	26.27	36.09	15.65	30.25
	60	0.250	11.70	47.79	3.95	7.63
	140	0.106	3.09	50.88	0.86	1.66
	200	0.075	0.22	51.10	0.64	1.24
	dry pan		0.01	51.11	0.63	
	wet pan			0.63	0.00	

d_{10} (mm): 0.26 d_{50} (mm): 0.56
 d_{16} (mm): 0.30 d_{80} (mm): 0.64
 d_{30} (mm): 0.42 d_{84} (mm): 1.00

Median Particle Diameter -- d_{50} (mm): 0.56
Uniformity Coefficient, C_u -- $[d_{80}/d_{10}]$ (mm): 2.5
Coefficient of Curvature, C_c -- $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 1.1
Mean Particle Diameter -- $[(d_{16} + d_{50} + d_{84})/3]$ (mm): 0.62

ASTM Soil Classification: Poorly-graded sand
USDA Soil Classification: Sand

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002335



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Hydrometer Data

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (31-32)
Ring Number: NA
Depth: NA

Type of Water Used: DISTILLED
Reaction with H_2O_2 : None
Dispersant: $(NaPO_3)_6$
Measured particle density: 2.66

Test Date: 31-Jan-03
Start Time: 8:42

Initial Wt. (g): 50.13
Total Sample Wt. (g): 1149.22
Wt. Passing #10 (g): 1113.40

Date	Time (min)	Temp (°C)	R (g/L)	R_L (g/L)	R_{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
4-Feb-03	1	21.0	8.0	6.5	1.5	15.0	0.05190	3.0	2.9
	2	21.0	8.0	6.5	1.5	15.0	0.03670	3.0	2.9
	5	21.0	8.0	6.5	1.5	15.0	0.02321	3.0	2.9
	10	21.0	7.5	6.5	1.0	15.1	0.01646	2.0	1.9
	20	21.0	7.5	6.5	1.0	15.1	0.01164	2.0	1.9
	60	21.0	7.0	6.5	0.5	15.2	0.00674	1.0	1.0
	120	21.0	6.5	6.0	0.5	15.2	0.00478	1.0	1.0
	240	21.0	6.5	6.0	0.5	15.2	0.00338	1.0	1.0
	480	21.0	6.5	6.0	0.5	15.2	0.00239	1.0	1.0
5-Feb-03	1440	21.0	6.4	6.0	0.4	15.3	0.00138	0.8	0.8

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Wet Sieve Data (#10 Split)

Job Name: Shaw Environmental Initial Dry Weight of Sample (g): 877.45
Job Number: WR03.0011.00 Weight Passing #10 (g): 877.45
Sample Number: MW-12 (46-47) Weight Retained #10 (g): 0.00
Ring Number: NA Weight of Hydrometer Sample (g): 50.10
Depth: NA Calculated Weight of Sieve Sample (g): 50.10
Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	877.45	100.00
	1.5"	38.1	0.00	0.00	877.45	100.00
	3/4"	19.0	0.00	0.00	877.45	100.00
	3/8"	9.5	0.00	0.00	877.45	100.00
	4	4.75	0.00	0.00	877.45	100.00
	10	2.00	0.00	0.00	877.45	100.00
-10	(Based on calculated sieve wt.)					
	20	0.85	0.15	0.15	49.95	99.70
	40	0.425	0.88	1.03	49.07	97.94
	60	0.250	1.90	2.93	47.17	94.15
	140	0.106	5.18	8.11	41.99	83.81
	200	0.075	3.31	11.42	38.68	77.21
	dry pan		1.64	13.06	37.04	
	wet pan			37.04	0.00	

d_{10} (mm): 0.0014 d_{50} (mm): 0.025
 d_{15} (mm): 0.0039 d_{60} (mm): 0.041
 d_{30} (mm): 0.010 d_{84} (mm): 0.11

Median Particle Diameter-- d_{50} (mm): 0.025
Uniformity Coefficient, C_u -- $[d_{60}/d_{10}]$ (mm): 29
Coefficient of Curvature, C_c -- $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 1.7
Mean Particle Diameter -- $[(d_{15} + d_{50} + d_{84})/3]$ (mm): 0.046

Classification of fines: ML

ASTM Soil Classification: Silt with sand
USDA Soil Classification: Silt Loam

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002338



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Hydrometer Data

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (46-47)
Ring Number: NA
Depth: NA

Test Date: 30-Jan-03
Start Time: 8:12

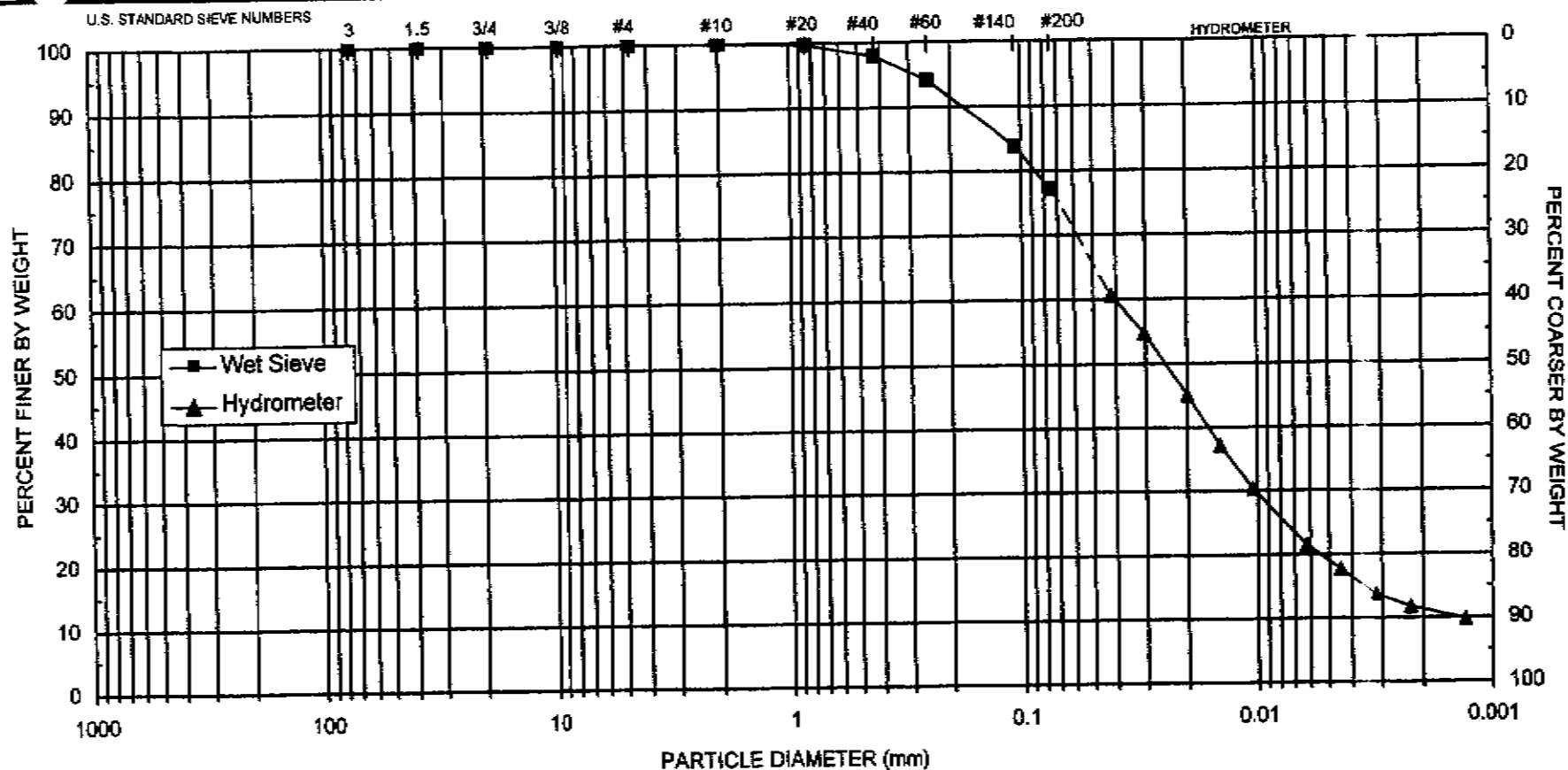
Type of Water Used: DISTILLED
Reaction with H_2O_2 : Moderate
Dispersant: $(NaPO_3)_6$
Measured particle density: 2.74

Initial Wt. (g): 50.10
Total Sample Wt. (g): 877.45
Wt. Passing #10 (g): 877.45

Date	Time (min)	Temp (°C)	R (g/L)	R_L (g/L)	R_{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
6-Feb-03	1	21.0	37.0	6.0	31.0	10.2	0.04195	60.6	60.6
	2	21.0	34.0	6.0	28.0	10.7	0.03037	54.8	54.8
	5	21.0	29.0	6.0	23.0	11.5	0.01993	45.0	45.0
	10	21.0	25.0	6.0	19.0	12.2	0.01449	37.2	37.2
	20	21.0	21.5	6.0	15.5	12.8	0.01048	30.3	30.3
	60	21.0	17.0	6.0	11.0	13.5	0.00622	21.5	21.5
	120	21.0	15.0	6.0	9.0	13.8	0.00445	17.6	17.6
	240	21.0	13.0	6.0	7.0	14.2	0.00319	13.7	13.7
	480	21.0	12.0	6.0	6.0	14.3	0.00227	11.7	11.7
7-Feb-03	1440	21.0	11.0	6.0	5.0	14.5	0.00132	9.8	9.8

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



UNIFIED

COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

USDA

COBBLES	GRAVEL		SAND					SILT	CLAY
			Very coarse	Coarse	Medium	Fine	Very fine		

$d_{10} = 0.0014$

$d_{30} = 0.010$

$d_{50} = 0.025$

$d_{60} = 0.041$

$C_u = 29$

$C_c = 1.7$

SAMPLE NUMBER

DEPTH

ASTM CLASSIFICATION

USDA CLASSIFICATION

MW-12 (46-47)

NA

Silt with sand

Silt Loam



Daniel B. Stephens & Associates, Inc.

LEU 002340



Daniel B. Stephens & Associates, Inc.

**Particle Size Analysis
Wet Sieve Data (#10 Split)**

Job Name: Shaw Environmental Initial Dry Weight of Sample (g): 1045.17
Job Number: WR03.0011.00 Weight Passing #10 (g): 1036.34
Sample Number: MW-15 (13.5-14.5) Weight Retained #10 (g): 8.83
Ring Number: NA Weight of Hydrometer Sample (g): 50.85
Depth: NA Calculated Weight of Sieve Sample (g): 51.28
Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	1045.17	100.00
	1.5"	38.1	0.00	0.00	1045.17	100.00
	3/4"	19.0	0.00	0.00	1045.17	100.00
	3/8"	9.5	0.00	0.00	1045.17	100.00
	4	4.75	0.00	0.00	1045.17	100.00
	10	2.00	8.83	8.83	1036.34	99.16
-10	(Based on calculated sieve wt.)					
	20	0.85	1.57	2.00	49.28	98.09
	40	0.425	2.76	4.76	46.52	90.71
	60	0.250	4.28	9.04	42.24	82.37
	140	0.106	10.31	19.35	31.93	62.26
	200	0.075	4.41	23.76	27.52	53.66
	dry pan		1.70	25.46	25.82	
	wet pan			25.82	0.00	

d_{10} (mm): 0.00019 d_{50} (mm): 0.064
 d_{16} (mm): 0.0041 d_{60} (mm): 0.097
 d_{30} (mm): 0.023 d_{84} (mm): 0.28

Median Particle Diameter— d_{50} (mm): 0.064
Uniformity Coefficient, C_u — $[d_{60}/d_{10}]$ (mm): 511
Coefficient of Curvature, C_c — $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 29
Mean Particle Diameter— $[(d_{16}+d_{50}+d_{84})/3]$ (mm): 0.12

Note: Reported values for d_{10} , C_u , C_c , and soil classification are estimates, since extrapolation was required to obtain the d_{10} diameter

Classification of fines: ML

ASTM Soil Classification: Sandy silt
USDA Soil Classification: Sandy Loam

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002341



Daniel B. Stephens & Associates, Inc.

**Particle Size Analysis
Hydrometer Data**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (13.5-14.5)
Ring Number: NA
Depth: NA

Test Date: 29-Jan-03
Start Time: 8:00

Type of Water Used: DISTILLED
Reaction with H₂O₂: Moderate
Dispersant: (NaPO₃)₆
Measured particle density: 2.77

Initial Wt. (g): 50.85
Total Sample Wt. (g): 1045.17
Wt. Passing #10 (g): 1036.34

Date	Time (min)	Temp (°C)	R (g/L)	R _L (g/L)	R _{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
6-Feb-03	1	21.0	27.5	6.0	21.5	11.8	0.04460	41.4	41.1
	2	21.0	24.0	6.0	18.0	12.4	0.03229	34.7	34.4
	5	21.0	21.0	6.0	15.0	12.9	0.02083	28.9	28.7
	10	21.0	19.0	6.0	13.0	13.2	0.01491	25.1	24.8
	20	21.0	18.0	6.0	12.0	13.3	0.01061	23.1	22.9
	60	21.0	15.0	6.0	9.0	13.8	0.00624	17.3	17.2
	120	21.0	14.5	6.0	8.5	13.9	0.00442	16.4	16.2
	240	21.0	14.0	6.0	8.0	14.0	0.00314	15.4	15.3
	480	21.0	13.5	6.0	7.5	14.1	0.00222	14.5	14.3
7-Feb-03	1440	21.0	13.0	6.0	7.0	14.2	0.00129	13.5	13.4

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis
Wet Sieve Data (#10 Split)

Job Name: Shaw Environmental Initial Dry Weight of Sample (g): 1401.97
Job Number: WR03.0011.00 Weight Passing #10 (g): 795.24
Sample Number: MW-15 (23.5-24.5) Weight Retained #10 (g): 606.73
Ring Number: NA Weight of Hydrometer Sample (g): 50.33
Depth: NA Calculated Weight of Sieve Sample (g): 88.73
Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10		75	0.00	0.00	1401.97	100.00
	3"	38.1	0.00	0.00	1401.97	100.00
	1.5"	19.0	145.03	145.03	1256.94	89.66
	3/4"	9.5	118.46	263.49	1138.48	81.21
	3/8"	4.75	135.22	398.71	1003.26	71.56
	4	2.00	208.02	606.73	795.24	56.72
	10					
-10			(Based on calculated sieve wt.)			
	20	0.85	9.14	47.54	41.19	46.42
	40	0.425	17.06	64.60	24.13	27.20
	60	0.250	13.11	77.71	11.02	12.42
	140	0.106	6.65	84.36	4.37	4.93
	200	0.075	1.23	85.59	3.14	3.54
	dry pan		0.29	85.88	2.85	
	wet pan			2.85	0.00	

d_{10} (mm): 0.19 d_{50} (mm): 1.1
 d_{16} (mm): 0.28 d_{80} (mm): 2.4
 d_{30} (mm): 0.47 d_{84} (mm): 12

Median Particle Diameter— d_{50} (mm): 1.1
Uniformity Coefficient, C_u — $[d_{80}/d_{10}]$ (mm): 13
Coefficient of Curvature, C_c — $[(d_{30})^2/(d_{10} \cdot d_{80})]$ (mm): 0.48
Mean Particle Diameter— $[(d_{16}+d_{50}+d_{84})/3]$ (mm): 4.5

ASTM Soil Classification: Poorly-graded sand with gravel
USDA Soil Classification: NA

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002344



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Hydrometer Data

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (23.5-24.5)
Ring Number: NA
Depth: NA

Test Date: 31-Jan-03
Start Time: 8:30

Type of Water Used: DISTILLED
Reaction with H_2O_2 : None
Dispersant: $(NaPO_3)_6$
Measured particle density: 2.66

Initial Wt. (g): 50.33
Total Sample Wt. (g): 1401.97
Wt. Passing #10 (g): 795.24

Date	Time (min)	Temp (°C)	R (g/L)	R _L (g/L)	R _{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
4-Feb-03	1	21.0	9.0	6.5	2.5	14.8	0.05171	5.0	2.8
	2	21.0	8.5	6.5	2.0	14.9	0.03667	4.0	2.3
	5	21.0	8.0	6.5	1.5	15.0	0.02325	3.0	1.7
	10	21.0	8.0	6.5	1.5	15.0	0.01644	3.0	1.7
	20	21.0	7.5	6.5	1.0	15.1	0.01166	2.0	1.1
	60	21.0	7.5	6.5	1.0	15.1	0.00673	2.0	1.1
	120	21.0	7.0	6.0	1.0	15.2	0.00477	2.0	1.1
	240	21.0	7.0	6.0	1.0	15.2	0.00337	2.0	1.1
	480	21.0	7.0	6.0	1.0	15.2	0.00239	2.0	1.1
5-Feb-03	1440	21.0	6.5	6.0	0.5	15.2	0.00138	1.0	0.6

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis
Wet Sieve Data (#10 Split)

Job Name: Shaw Environmental Initial Dry Weight of Sample (g): 643.46
Job Number: WR03.0011.00 Weight Passing #10 (g): 643.46
Sample Number: MW-15 (28.5-29.5) Weight Retained #10 (g): 0.00
Ring Number: NA Weight of Hydrometer Sample (g): 50.67
Depth: NA Calculated Weight of Sieve Sample (g): 50.67
Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	643.46	100.00
	1.5"	38.1	0.00	0.00	643.46	100.00
	3/4"	19.0	0.00	0.00	643.46	100.00
	3/8"	9.5	0.00	0.00	643.46	100.00
	4	4.75	0.00	0.00	643.46	100.00
	10	2.00	0.00	0.00	643.46	100.00
-10	(Based on calculated sieve wt.)					
	20	0.85	0.02	0.02	50.65	99.96
	40	0.425	0.15	0.17	50.50	99.66
	60	0.250	0.74	0.91	49.76	98.20
	140	0.106	4.13	5.04	45.63	90.05
	200	0.075	2.98	8.02	42.65	84.17
	dry pan		1.38	9.40	41.27	
	wet pan			41.27	0.00	

d_{10} (mm): 0.0014 d_{50} (mm): 0.019
 d_{16} (mm): 0.0038 d_{60} (mm): 0.025
 d_{30} (mm): 0.0085 d_{84} (mm): 0.074

Median Particle Diameter— d_{50} (mm): 0.019
Uniformity Coefficient, C_u — $[d_{60}/d_{10}]$ (mm): 18
Coefficient of Curvature, C_c — $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 2.1
Mean Particle Diameter— $[(d_{16}+d_{50}+d_{84})/3]$ (mm): 0.032

Classification of fines (visual method): ML

ASTM Soil Classification: Silt with sand
USDA Soil Classification: Silt Loam

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002347



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Hydrometer Data

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (28.5-29.5)
Ring Number: NA
Depth: NA

Test Date: 30-Jan-03
Start Time: 8:54

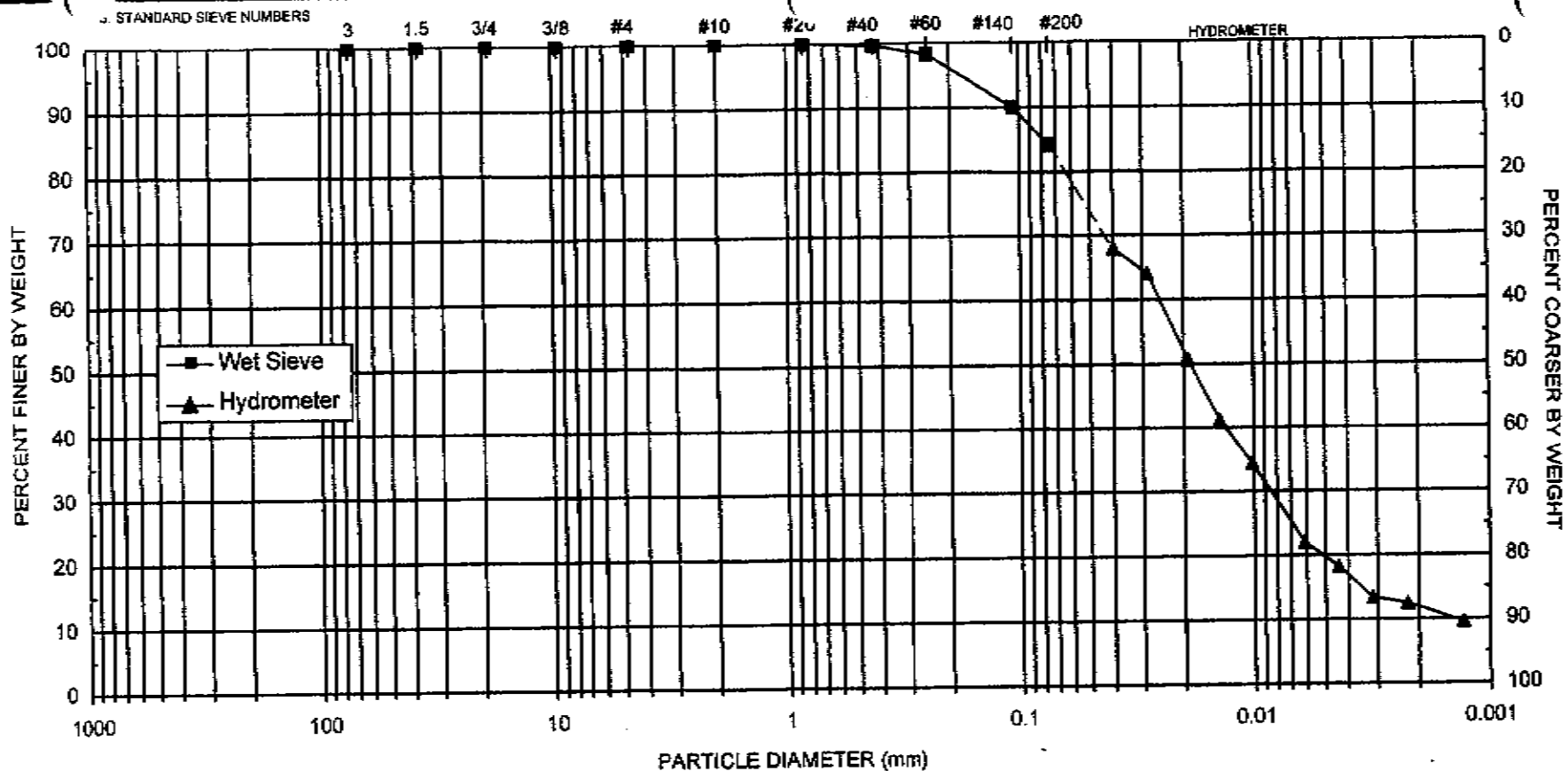
Type of Water Used: DISTILLED
Reaction with H_2O_2 : None
Dispersant: $(NaPO_3)_6$
Measured particle density: 2.78

Initial Wt. (g): 50.67
Total Sample Wt. (g): 643.46
Wt. Passing #10 (g): 643.46

Date	Time (min)	Temp (°C)	R (g/L)	R_L (g/L)	R_{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
4-Feb-03	1	21.0	42.0	6.5	35.5	9.4	0.03978	68.0	68.0
	2	21.0	40.0	6.5	33.5	9.7	0.02861	64.1	64.1
	5	21.0	33.0	6.5	26.5	10.9	0.01913	50.7	50.7
	10	21.0	28.0	6.5	21.5	11.7	0.01403	41.2	41.2
	20	21.0	24.5	6.5	18.0	12.3	0.01016	34.5	34.5
	60	21.0	18.0	6.5	11.5	13.3	0.00611	22.0	22.0
	120	21.0	15.5	6.0	9.5	13.8	0.00439	18.2	18.2
	240	21.0	13.0	6.0	7.0	14.2	0.00315	13.4	13.4
	480	21.0	12.5	6.0	6.5	14.3	0.00223	12.4	12.4
5-Feb-03	1440	21.0	11.0	6.0	5.0	14.5	0.00130	9.6	9.6

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



UNIFIED	COBBLES	GRAVEL		SAND			SILT OR CLAY			
		Coarse	Fine	Coarse	Medium	Fine				
USDA	COBBLES	GRAVEL		SAND					SILT	CLAY
				Very coarse	Coarse	Medium	Fine	Very fine		

$d_{10} = 0.0014$	$d_{30} = 0.0085$	$d_{50} = 0.019$	$d_{60} = 0.025$	$C_u = 18$	$C_c = 2.1$
SAMPLE NUMBER		DEPTH	ASTM CLASSIFICATION		USDA CLASSIFICATION
MW-15 (28.5-29.5)		NA	Silt with sand		Silt Loam



Daniel B. Stephens & Associates, Inc.

LEU 002349



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Wet Sieve Data (#10 Split)

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (38.5-39.5)
Ring Number: NA
Depth: NA

Initial Dry Weight of Sample (g): 746.94
Weight Passing #10 (g): 739.03
Weight Retained #10 (g): 7.91
Weight of Hydrometer Sample (g): 50.24
Calculated Weight of Sieve Sample (g): 50.78

Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	746.94	100.00
	1.5"	38.1	0.00	0.00	746.94	100.00
	3/4"	19.0	0.00	0.00	746.94	100.00
	3/8"	9.5	0.00	0.00	746.94	100.00
	4	4.75	0.25	0.25	746.69	99.97
	10	2.00	7.66	7.91	739.03	98.94
-10	(Based on calculated sieve wt.)					
	20	0.85	0.70	1.24	49.54	97.56
	40	0.425	0.44	1.68	49.10	96.70
	60	0.250	0.17	1.85	48.93	96.36
	140	0.106	0.40	2.25	48.53	95.57
	200	0.075	0.68	2.93	47.85	94.23
	dry pan		0.64	3.57	47.21	
	wet pan			47.21	0.00	

d_{10} (mm): 0.0010

d_{50} (mm): 0.014

d_{16} (mm): 0.0024

d_{80} (mm): 0.020

d_{30} (mm): 0.0071

d_{84} (mm): 0.037

Median Particle Diameter— d_{50} (mm): 0.014

Uniformity Coefficient, C_u — $[d_{80}/d_{10}]$ (mm): 20

Coefficient of Curvature, C_c — $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 2.5

Mean Particle Diameter— $[(d_{16}+d_{50}+d_{84})/3]$ (mm): 0.018

Note: Reported values for d_{10} , C_u , C_c , and soil classification are estimates, since extrapolation was required to obtain the d_{10} diameter

Classification of fines (visual method): ML

ASTM Soil Classification: Silt

USDA Soil Classification: Silt Loam

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: D. O'Dowd

LEU 002350



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Hydrometer Data

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (38.5-39.5)
Ring Number: NA
Depth: NA

Test Date: 31-Jan-03
Start Time: 8:48

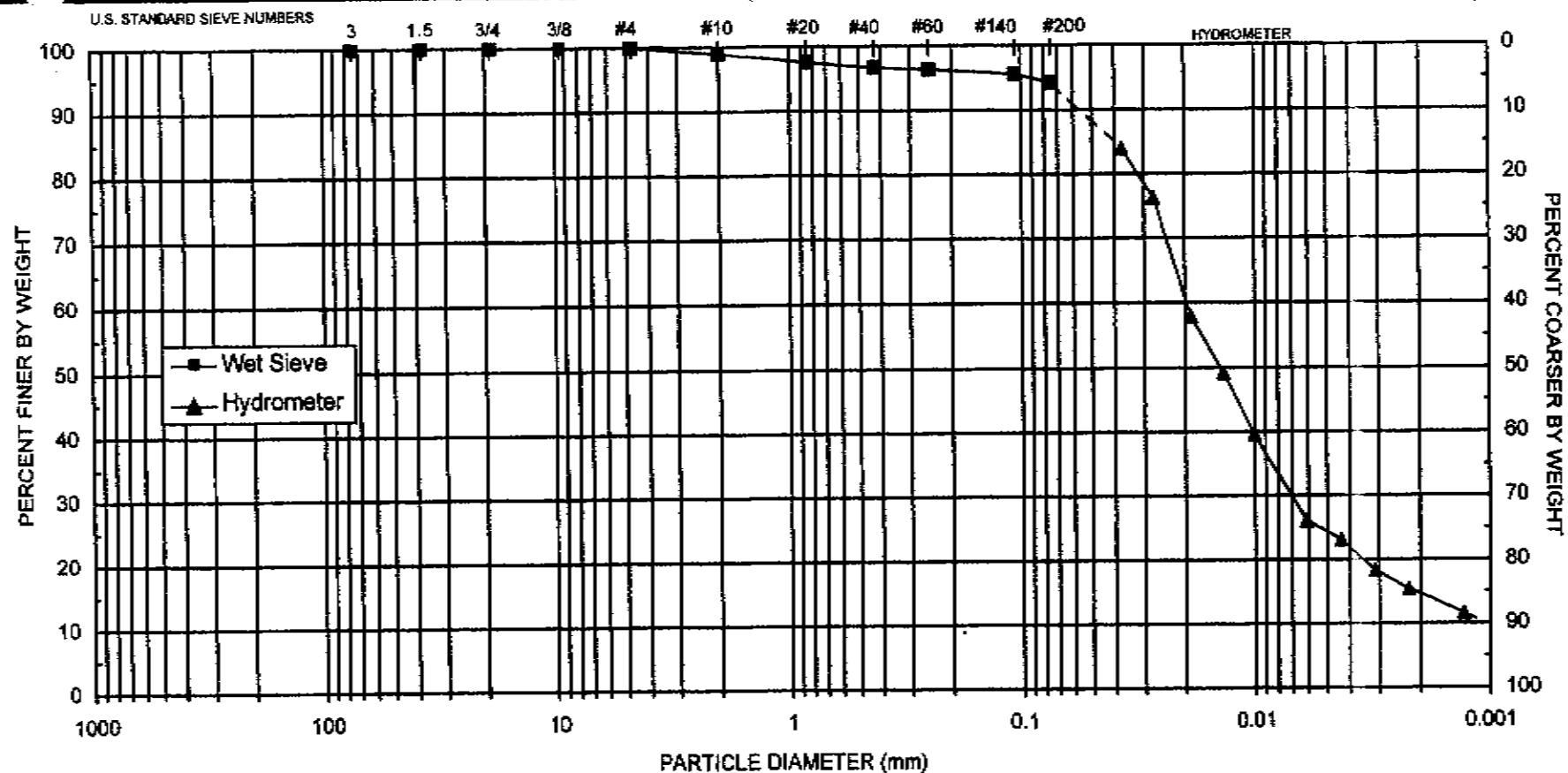
Type of Water Used: DISTILLED
Reaction with H_2O_2 : None
Dispersant: $(NaPO_3)_6$
Measured particle density: 2.75

Initial Wt. (g): 50.24
Total Sample Wt. (g): 746.94
Wt. Passing #10 (ϕ): 739.03

Date	Time (min)	Temp (°C)	R (g/L)	R _L (g/L)	R _{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
4-Feb-03	1	21.0	50.0	6.5	43.5	8.1	0.03722	84.9	84.0
	2	21.0	46.0	6.5	39.5	8.8	0.02736	77.1	76.2
	5	21.0	36.5	6.5	30.0	10.3	0.01878	58.5	57.9
	10	21.0	32.0	6.5	25.5	11.1	0.01375	49.7	49.2
	20	21.0	27.0	6.5	20.5	11.9	0.01008	40.0	39.6
	60	21.0	20.0	6.5	13.5	13.0	0.00609	26.3	26.1
	120	21.0	18.0	6.0	12.0	13.3	0.00436	23.4	23.2
	240	21.0	15.5	6.0	9.5	13.8	0.00313	18.5	18.3
	480	21.0	14.0	6.0	8.0	14.0	0.00223	15.6	15.4
5-Feb-03	1440	21.0	12.0	6.0	6.0	14.3	0.00130	11.7	11.6

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



UNIFIED	COBBLES	GRAVEL		SAND			SILT OR CLAY			
		Coarse	Fine	Coarse	Medium	Fine				
USDA	COBBLES	GRAVEL		SAND					SILT	CLAY
				Very coarse	Coarse	Medium	Fine	Very fine		

$d_{10} = 0.0010$ $d_{30} = 0.0071$ $d_{50} = 0.014$ $d_{60} = 0.020$ $C_u = 20$ $C_c = 2.5$

SAMPLE NUMBER

DEPTH

ASTM CLASSIFICATION

USDA CLASSIFICATION

MW-15 (38.5-39.5)

NA

Silt

Silt Loam

Note: Reported values for d_{10} , C_u , C_c , and ASTM classification are estimates, since extrapolation was required to obtain the d_{10} diameter



Daniel B. Stephens & Associates, Inc.

LEU 002352



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis
Wet Sieve Data (#10 Split)

Job Name: Shaw Environmental Initial Dry Weight of Sample (g): 669.90
Job Number: WR03.0011.00 Weight Passing #10 (g): 669.38
Sample Number: MW-16 (13.5-14.5) Weight Retained #10 (g): 0.52
Ring Number: NA Weight of Hydrometer Sample (g): 50.40
Depth: NA Calculated Weight of Sieve Sample (g): 50.44
Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	669.90	100.00
	1.5"	38.1	0.00	0.00	669.90	100.00
	3/4"	19.0	0.00	0.00	669.90	100.00
	3/8"	9.5	0.00	0.00	669.90	100.00
	4	4.75	0.00	0.00	669.90	100.00
	10	2.00	0.52	0.52	669.38	99.92
-10	(Based on calculated sieve wt.)					
	20	0.85	0.79	0.83	49.61	98.36
	40	0.425	3.24	4.07	46.37	91.93
	60	0.250	2.97	7.04	43.40	86.04
	140	0.106	6.63	13.67	36.77	72.90
	200	0.075	4.84	18.51	31.93	63.30
	dry pan		1.90	20.41	30.03	
	wet pan			30.03	0.00	

d_{10} (mm): 3.3E-05 d_{50} (mm): 0.049
 d_{16} (mm): 0.00096 d_{60} (mm): 0.068
 d_{30} (mm): 0.016 d_{84} (mm): 0.22

Median Particle Diameter — d_{50} (mm): 0.049
Uniformity Coefficient, C_u — $[d_{60}/d_{10}]$ (mm): 2061
Coefficient of Curvature, C_c — $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 114
Mean Particle Diameter — $[(d_{16} + d_{50} + d_{84})/3]$ (mm): 0.090

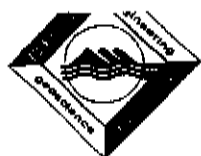
Note: Reported values for d_{10} , C_u , C_c , and soil classification are estimates, since extrapolation was required to obtain the d_{10} diameter

Classification of fines: CL

ASTM Soil Classification: Sandy lean clay
USDA Soil Classification: Loam

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002353



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Hydrometer Data

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (13.5-14.5)
Ring Number: NA
Depth: NA

Test Date: 30-Jan-03
Start Time: 8:06

Type of Water Used: DISTILLED
Reaction with H_2O_2 : Moderate
Dispersant: $(NaPO_3)_6$
Measured particle density: 2.75

Initial Wt. (g): 50.40
Total Sample Wt. (g): 669.90
Wt. Passing #10 (g): 669.38

Date	Time (min)	Temp (°C)	R (g/L)	R _L (g/L)	R _{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
6-Feb-03	1	21.0	30.0	6.0	24.0	11.4	0.04410	46.7	46.6
	2	21.0	26.0	6.0	20.0	12.0	0.03207	38.9	38.9
	5	21.0	23.0	6.0	17.0	12.5	0.02069	33.1	33.0
	10	21.0	21.0	6.0	15.0	12.9	0.01482	29.2	29.1
	20	21.0	19.5	6.0	13.5	13.1	0.01058	26.3	26.2
	60	21.0	18.0	6.0	12.0	13.3	0.00617	23.3	23.3
	120	21.0	17.0	6.0	11.0	13.5	0.00439	21.4	21.4
	240	21.0	16.0	6.0	10.0	13.7	0.00312	19.4	19.4
	480	21.0	15.0	6.0	9.0	13.8	0.00222	17.5	17.5
7-Feb-03	1440	21.0	14.5	6.0	8.5	13.9	0.00129	16.5	16.5

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002354



Daniel B. Stephens & Associates, Inc.

**Particle Size Analysis
Wet Sieve Data (#10 Split)**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (23.5-24.5)
Ring Number: NA
Depth: NA

Initial Dry Weight of Sample (g): 1463.17
Weight Passing #10 (g): 1262.73
Weight Retained #10 (g): 200.44
Weight of Hydrometer Sample (g): 50.39
Calculated Weight of Sieve Sample (g): 58.39

Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	1463.17	100.00
	1.5"	38.1	0.00	0.00	1463.17	100.00
	3/4"	19.0	0.00	0.00	1463.17	100.00
	3/8"	9.5	10.23	10.23	1452.94	99.30
	4	4.75	41.30	51.53	1411.64	96.48
	10	2.00	148.91	200.44	1262.73	86.30
-10	(Based on calculated sieve wt.)					
	20	0.85	11.88	19.88	38.51	65.95
	40	0.425	16.33	36.21	22.18	37.99
	60	0.250	7.84	44.05	14.34	24.56
	140	0.106	7.13	51.18	7.21	12.35
	200	0.075	1.62	52.80	5.59	9.57
	dry pan		0.36	53.16	5.23	
	wet pan			5.23	0.00	

d_{10} (mm): 0.079

d_{50} (mm): 0.57

d_{16} (mm): 0.14

d_{80} (mm): 0.73

d_{30} (mm): 0.31

d_{84} (mm): 1.8

Median Particle Diameter— d_{50} (mm): 0.57

Uniformity Coefficient, C_u — $[d_{80}/d_{10}]$ (mm): 9.2

Coefficient of Curvature, C_c — $[(d_{30})^2/(d_{10} \cdot d_{80})]$ (mm): 1.7

Mean Particle Diameter— $[(d_{16}+d_{50}+d_{84})/3]$ (mm): 0.84

Classification of fines (visual method): ML

ASTM Soil Classification: Well-graded sand with silt

USDA Soil Classification: Loamy Sand

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: D. O'Dowd

LEU 002356



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Hydrometer Data

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (23.5-24.5)
Ring Number: NA
Depth: NA

Test Date: 30-Jan-03
Start Time: 8:36

Type of Water Used: DISTILLED
Reaction with H_2O_2 : None
Dispersant: $(NaPO_3)_6$
Measured particle density: 2.64

Initial Wt. (g): 50.39
Total Sample Wt. (g): 1463.17
Wt. Passing #10 (g): 1262.73

Date	Time (min)	Temp (°C)	R (g/L)	R _L (g/L)	R _{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
6-Feb-03	1	21.0	10.0	6.0	4.0	14.7	0.05167	7.9	6.9
	2	21.0	9.0	6.0	3.0	14.8	0.03674	6.0	5.1
	5	21.0	8.5	6.0	2.5	14.9	0.02330	5.0	4.3
	10	21.0	8.0	6.0	2.0	15.0	0.01652	4.0	3.4
	20	21.0	8.0	6.0	2.0	15.0	0.01168	4.0	3.4
	60	21.0	7.5	6.0	1.5	15.1	0.00676	3.0	2.6
	120	21.0	7.5	6.0	1.5	15.1	0.00478	3.0	2.6
	240	21.0	7.5	6.0	1.5	15.1	0.00338	3.0	2.6
	480	21.0	7.0	6.0	1.0	15.2	0.00240	2.0	1.7
7-Feb-03	1440	21.0	6.5	6.0	0.5	15.2	0.00139	1.0	0.9

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002357



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis Wet Sieve Data (#10 Split)

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (28.5-29.5)
Ring Number: NA
Depth: NA

Initial Dry Weight of Sample (g): 959.86
Weight Passing #10 (g): 959.86
Weight Retained #10 (g): 0.00
Weight of Hydrometer Sample (g): 50.95
Calculated Weight of Sieve Sample (g): 50.95

Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10	3"	75	0.00	0.00	959.86	100.00
	1.5"	38.1	0.00	0.00	959.86	100.00
	3/4"	19.0	0.00	0.00	959.86	100.00
	3/8"	9.5	0.00	0.00	959.86	100.00
	4	4.75	0.00	0.00	959.86	100.00
	10	2.00	0.00	0.00	959.86	100.00
-10				(Based on calculated sieve wt.)		
	20	0.85	0.04	0.04	50.91	99.92
	40	0.425	0.31	0.35	50.60	99.31
	60	0.250	1.49	1.84	49.11	96.39
	140	0.106	5.63	7.47	43.48	85.34
	200	0.075	2.68	10.15	40.80	80.08
	dry pan		0.86	11.01	39.94	
	wet pan			39.94	0.00	

d_{10} (mm): 0.00033

d_{50} (mm): 0.015

d_{16} (mm): 0.0010

d_{60} (mm): 0.027

d_{30} (mm): 0.0043

d_{84} (mm): 0.097

Median Particle Diameter — d_{50} (mm): 0.015

Uniformity Coefficient, C_u — $[d_{60}/d_{10}]$ (mm): 82

Coefficient of Curvature, C_c — $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 2.1

Mean Particle Diameter — $[(d_{16} + d_{50} + d_{84})/3]$ (mm): 0.038

Note: Reported values for d_{10} , C_u , C_c , and soil classification are estimates, since extrapolation was required to obtain the d_{10} diameter

Classification of fines: CL

ASTM Soil Classification: Lean clay with sand

USDA Soil Classification: Silt Loam

Laboratory analysis by: D. O'Dowd

Data entered by: D. O'Dowd

Checked by: D. O'Dowd

LEU 002359



Daniel B. Stephens & Associates, Inc.

Particle Size Analysis
Wet Sieve Data (#10 Split)

Job Name: Shaw Environmental Initial Dry Weight of Sample (g): 902.60
Job Number: WR03.0011.00 Weight Passing #10 (g): 902.23
Sample Number: MW-16 (38.5-39.5) Weight Retained #10 (g): 0.37
Ring Number: NA Weight of Hydrometer Sample (g): 50.74
Depth: NA Calculated Weight of Sieve Sample (g): 50.76

Test Date: 28-Jan-03

Test Fraction	Sieve Number	Diameter (mm)	Wt. Retained	Cum Wt. Retained	Wt. Passing	% Passing
+10						
	3"	75	0.00	0.00	902.60	100.00
	1.5"	38.1	0.00	0.00	902.60	100.00
	3/4"	19.0	0.00	0.00	902.60	100.00
	3/8"	9.5	0.00	0.00	902.60	100.00
	4	4.75	0.00	0.00	902.60	100.00
	10	2.00	0.37	0.37	902.23	99.96
-10			(Based on calculated sieve wt.)			
	20	0.85	0.01	0.03	50.73	99.94
	40	0.425	0.02	0.05	50.71	99.90
	60	0.250	0.03	0.08	50.68	99.84
	140	0.106	1.19	1.27	49.49	97.50
	200	0.075	3.44	4.71	46.05	90.72
	dry pan		4.29	9.00	41.76	
	wet pan			41.76	0.00	

d_{10} (mm): 0.0040 d_{50} (mm): 0.027
 d_{16} (mm): 0.0080 d_{60} (mm): 0.033
 d_{30} (mm): 0.016 d_{84} (mm): 0.062

Median Particle Diameter— d_{50} (mm): 0.027
Uniformity Coefficient, C_u — $[d_{60}/d_{10}]$ (mm): 8.3
Coefficient of Curvature, C_c — $[(d_{30})^2/(d_{10} \cdot d_{60})]$ (mm): 1.9
Mean Particle Diameter— $[(d_{16}+d_{50}+d_{84})/3]$ (mm): 0.032

Classification of fines (visual method): ML

ASTM Soil Classification: Silt
USDA Soil Classification: Silt Loam

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002360



Daniel B. Stephens & Associates, Inc.

**Particle Size Analysis
Hydrometer Data**

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (38.5-39.5)
Ring Number: NA
Depth: NA

Type of Water Used: DISTILLED
Reaction with H₂O₂: Weak
Dispersant: (NaPO₃)₆
Measured particle density: 2.74
Initial Wt. (g): 50.74
Total Sample Wt. (g): 902.60
Wt. Passing #10 (g): 902.23

Test Date: 30-Jan-03
Start Time: 8:24

Date	Time (min)	Temp (°C)	R (g/L)	R _L (g/L)	R _{corr} (g/L)	L (cm)	D (mm)	P (%)	% Finer
6-Feb-03	1	21.0	42.0	6.0	36.0	9.4	0.04025	69.5	69.5
	2	21.0	35.0	6.0	29.0	10.6	0.03015	56.0	56.0
	5	21.0	25.5	6.0	19.5	12.1	0.02043	37.7	37.6
	10	21.0	20.0	6.0	14.0	13.0	0.01497	27.0	27.0
	20	21.0	16.0	6.0	10.0	13.7	0.01085	19.3	19.3
	60	21.0	13.0	6.0	7.0	14.2	0.00638	13.5	13.5
	120	21.0	12.0	6.0	6.0	14.3	0.00453	11.6	11.6
	240	21.0	10.0	6.0	4.0	14.7	0.00324	7.7	7.7
	480	21.0	9.5	6.0	3.5	14.7	0.00230	6.8	6.8
7-Feb-03	1440	21.0	9.0	6.0	3.0	14.8	0.00133	5.8	5.8

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Summary of Particle Density Tests

Sample Number	Particle Density (g/cm ³)
MW-12 (13.5-14.5)	2.77
MW-12 (21-22)	2.65
MW-12 (31-32)	2.66
MW-12 (46-47)	2.74
MW-15 (13.5-14.5)	2.77
MW-15 (23.5-24.5)	2.66
MW-15 (28.5-29.5)	2.78
MW-15 (38.5-39.5)	2.75
MW-16 (13.5-14.5)	2.75
MW-16 (23.5-24.5)	2.64
MW-16 (28.5-29.5)	2.74
MW-16 (38.5-39.5)	2.74



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (13.5-14.5)
Ring Number: NA
Depth: NA
Test Date: 18-Feb-03

Trial 1

Weight of pycnometer filled w/air (g):	99.95
Weight of pycnometer filled w/soil (g):	151.72
Weight of pycnometer filled w/soil & water (g):	381.83
Weight of pycnometer filled w/water (g):	348.67
Observed temperature (°C):	29.00
Density of water at observed temperature (g/cm ³):	0.9960
Particle Density (g/cm ³):	2.77
Correction factor, K:	0.9978
Particle Density at 20°C (g/cm ³):	2.78

Trial 2

Weight of pycnometer filled w/air (g):	95.48
Weight of pycnometer filled w/soil (g):	147.20
Weight of pycnometer filled w/soil & water (g):	377.20
Weight of pycnometer filled w/water (g):	344.20
Observed temperature (°C):	29.00
Density of water at observed temperature (g/cm ³):	0.9960
Particle Density (g/cm ³):	2.75
Correction factor, K:	0.9978
Particle Density at 20°C (g/cm ³):	2.76

Average Particle Density (g/cm³): 2.77

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002364



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (21-22)
Ring Number: NA
Depth: NA
Test Date: 13-Feb-03

Trial 1

Weight of pycnometer filled w/air (g):	85.79
Weight of pycnometer filled w/soil (g):	136.45
Weight of pycnometer filled w/soil & water (g):	366.27
Weight of pycnometer filled w/water (g):	334.69
Observed temperature (°C):	27.00
Density of water at observed temperature (g/cm ³):	0.9965
Particle Density (g/cm ³):	2.65
Correction factor, K:	0.9983
Particle Density at 20°C (g/cm ³):	2.65

Trial 2

Weight of pycnometer filled w/air (g):	88.49
Weight of pycnometer filled w/soil (g):	140.24
Weight of pycnometer filled w/soil & water (g):	369.60
Weight of pycnometer filled w/water (g):	337.28
Observed temperature (°C):	27.00
Density of water at observed temperature (g/cm ³):	0.9965
Particle Density (g/cm ³):	2.65
Correction factor, K:	0.9983
Particle Density at 20°C (g/cm ³):	2.66

Average Particle Density (g/cm³): 2.65

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002365



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (31-32)
Ring Number: NA
Depth: NA
Test Date: 13-Feb-03

Trial 1

Weight of pycnometer filled w/air (g):	85.92
Weight of pycnometer filled w/soil (g):	137.07
Weight of pycnometer filled w/soil & water (g):	366.79
Weight of pycnometer filled w/water (g):	334.78
Observed temperature (°C):	27.00
Density of water at observed temperature (g/cm ³):	0.9965
Particle Density (g/cm ³):	2.66
Correction factor, K:	0.9983
Particle Density at 20°C (g/cm ³):	2.67

Trial 2

Weight of pycnometer filled w/air (g):	85.32
Weight of pycnometer filled w/soil (g):	136.49
Weight of pycnometer filled w/soil & water (g):	366.14
Weight of pycnometer filled w/water (g):	334.19
Observed temperature (°C):	27.00
Density of water at observed temperature (g/cm ³):	0.9965
Particle Density (g/cm ³):	2.65
Correction factor, K:	0.9983
Particle Density at 20°C (g/cm ³):	2.66

Average Particle Density (g/cm³): 2.66

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (46-47)
Ring Number: NA
Depth: NA
Test Date: 19-Feb-03

Trial 1

Weight of pycnometer filled w/air (g):	85.80
Weight of pycnometer filled w/soil (g):	137.61
Weight of pycnometer filled w/soil & water (g):	367.55
Weight of pycnometer filled w/water (g):	334.60
Observed temperature (°C):	28.50
Density of water at observed temperature (g/cm ³):	0.9961
Particle Density (g/cm ³):	2.74
Correction factor, K:	0.9979
Particle Density at 20°C (g/cm ³):	2.74

Trial 2

Weight of pycnometer filled w/air (g):	88.49
Weight of pycnometer filled w/soil (g):	139.32
Weight of pycnometer filled w/soil & water (g):	369.44
Weight of pycnometer filled w/water (g):	337.18
Observed temperature (°C):	28.50
Density of water at observed temperature (g/cm ³):	0.9961
Particle Density (g/cm ³):	2.73
Correction factor, K:	0.9979
Particle Density at 20°C (g/cm ³):	2.73

Average Particle Density (g/cm³): 2.74

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002367



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (13.5-14.5)
Ring Number: NA
Depth: NA
Test Date: 19-Feb-03

Trial 1

Weight of pycnometer filled w/air (g):	99.95
Weight of pycnometer filled w/soil (g):	151.40
Weight of pycnometer filled w/soil & water (g):	381.59
Weight of pycnometer filled w/water (g):	348.70
Observed temperature (°C):	28.50
Density of water at observed temperature (g/cm ³):	0.9961
Particle Density (g/cm ³):	2.76
Correction factor, K:	0.9979
Particle Density at 20°C (g/cm ³):	2.77

Trial 2

Weight of pycnometer filled w/air (g):	95.78
Weight of pycnometer filled w/soil (g):	146.99
Weight of pycnometer filled w/soil & water (g):	377.18
Weight of pycnometer filled w/water (g):	344.38
Observed temperature (°C):	28.50
Density of water at observed temperature (g/cm ³):	0.9961
Particle Density (g/cm ³):	2.77
Correction factor, K:	0.9979
Particle Density at 20°C (g/cm ³):	2.78

Average Particle Density (g/cm³): 2.77

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (23.5-24.5)
Ring Number: NA
Depth: NA
Test Date: 13-Feb-03

Trial 1

<i>Weight of pycnometer filled w/air (g):</i>	85.80
<i>Weight of pycnometer filled w/soil (g):</i>	138.72
<i>Weight of pycnometer filled w/soil & water (g):</i>	367.57
<i>Weight of pycnometer filled w/water (g):</i>	334.53
<i>Observed temperature (°C):</i>	29.50
<i>Density of water at observed temperature (g/cm³):</i>	0.9958
<i>Particle Density (g/cm³):</i>	2.65
<i>Correction factor, K:</i>	0.9976
<i>Particle Density at 20°C (g/cm³):</i>	2.66

Trial 2

<i>Weight of pycnometer filled w/air (g):</i>	88.49
<i>Weight of pycnometer filled w/soil (g):</i>	141.24
<i>Weight of pycnometer filled w/soil & water (g):</i>	370.03
<i>Weight of pycnometer filled w/water (g):</i>	337.11
<i>Observed temperature (°C):</i>	29.50
<i>Density of water at observed temperature (g/cm³):</i>	0.9958
<i>Particle Density (g/cm³):</i>	2.65
<i>Correction factor, K:</i>	0.9976
<i>Particle Density at 20°C (g/cm³):</i>	2.66

Average Particle Density (g/cm³): 2.66

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002369



Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (28.5-29.5)
Ring Number: NA
Depth: NA
Test Date: 13-Feb-03

Trial 1

Weight of pycnometer filled w/air (g):	95.49
Weight of pycnometer filled w/soil (g):	146.41
Weight of pycnometer filled w/soil & water (g):	376.80
Weight of pycnometer filled w/water (g):	344.32
Observed temperature (°C):	27.00
Density of water at observed temperature (g/cm ³):	0.9965
Particle Density (g/cm ³):	2.75
Correction factor, K:	0.9983
Particle Density at 20°C (g/cm ³):	2.76

Trial 2

Weight of pycnometer filled w/air (g):	95.78
Weight of pycnometer filled w/soil (g):	146.84
Weight of pycnometer filled w/soil & water (g):	377.34
Weight of pycnometer filled w/water (g):	344.48
Observed temperature (°C):	27.00
Density of water at observed temperature (g/cm ³):	0.9965
Particle Density (g/cm ³):	2.80
Correction factor, K:	0.9983
Particle Density at 20°C (g/cm ³):	2.80

Average Particle Density (g/cm³): 2.78

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (38.5-39.5)
Ring Number: NA
Depth: NA
Test Date: 13-Feb-03

Trial 1

<i>Weight of pycnometer filled w/air (g):</i>	92.45
<i>Weight of pycnometer filled w/soil (g):</i>	143.96
<i>Weight of pycnometer filled w/soil & water (g):</i>	373.76
<i>Weight of pycnometer filled w/water (g):</i>	340.98
<i>Observed temperature (°C):</i>	27.00
<i>Density of water at observed temperature (g/cm³):</i>	0.9965
<i>Particle Density (g/cm³):</i>	2.74
<i>Correction factor, K:</i>	0.9983
<i>Particle Density at 20°C (g/cm³):</i>	2.74

Trial 2

<i>Weight of pycnometer filled w/air (g):</i>	99.95
<i>Weight of pycnometer filled w/soil (g):</i>	151.77
<i>Weight of pycnometer filled w/soil & water (g):</i>	381.79
<i>Weight of pycnometer filled w/water (g):</i>	348.78
<i>Observed temperature (°C):</i>	27.00
<i>Density of water at observed temperature (g/cm³):</i>	0.9965
<i>Particle Density (g/cm³):</i>	2.75
<i>Correction factor, K:</i>	0.9983
<i>Particle Density at 20°C (g/cm³):</i>	2.75

Average Particle Density (g/cm³): 2.75

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002371



Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (13.5-14.5)
Ring Number: NA
Depth: NA
Test Date: 19-Feb-03

Trial 1

Weight of pycnometer filled w/air (g):	85.93
Weight of pycnometer filled w/soil (g):	136.55
Weight of pycnometer filled w/soil & water (g):	367.00
Weight of pycnometer filled w/water (g):	334.68
Observed temperature (°C):	28.50
Density of water at observed temperature (g/cm ³):	0.9961
Particle Density (g/cm ³):	2.76
Correction factor, K:	0.9979
Particle Density at 20°C (g/cm ³):	2.76

Trial 2

Weight of pycnometer filled w/air (g):	92.44
Weight of pycnometer filled w/soil (g):	143.77
Weight of pycnometer filled w/soil & water (g):	373.65
Weight of pycnometer filled w/water (g):	341.05
Observed temperature (°C):	28.50
Density of water at observed temperature (g/cm ³):	0.9961
Particle Density (g/cm ³):	2.73
Correction factor, K:	0.9979
Particle Density at 20°C (g/cm ³):	2.74

Average Particle Density (g/cm³): 2.75

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (23.5-24.5)
Ring Number: NA
Depth: NA
Test Date: 17-Feb-03

Trial 1

Weight of pycnometer filled w/air (g):	85.79
Weight of pycnometer filled w/soil (g):	136.87
Weight of pycnometer filled w/soil & water (g):	366.34
Weight of pycnometer filled w/water (g):	334.57
Observed temperature (°C):	29.00
Density of water at observed temperature (g/cm ³):	0.9960
Particle Density (g/cm ³):	2.63
Correction factor, K:	0.9978
Particle Density at 20°C (g/cm ³):	2.64

Trial 2

Weight of pycnometer filled w/air (g):	88.47
Weight of pycnometer filled w/soil (g):	139.90
Weight of pycnometer filled w/soil & water (g):	369.13
Weight of pycnometer filled w/water (g):	337.14
Observed temperature (°C):	29.00
Density of water at observed temperature (g/cm ³):	0.9960
Particle Density (g/cm ³):	2.64
Correction factor, K:	0.9978
Particle Density at 20°C (g/cm ³):	2.64

Average Particle Density (g/cm³): 2.64

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002373



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (28.5-29.5)
Ring Number: NA
Depth: NA
Test Date: 17-Feb-03

Trial 1

<i>Weight of pycnometer filled w/air (g):</i>	85.92
<i>Weight of pycnometer filled w/soil (g):</i>	136.35
<i>Weight of pycnometer filled w/soil & water (g):</i>	366.62
<i>Weight of pycnometer filled w/water (g):</i>	334.64
<i>Observed temperature (°C):</i>	29.00
<i>Density of water at observed temperature (g/cm³):</i>	0.9960
<i>Particle Density (g/cm³):</i>	2.72
<i>Correction factor, K:</i>	0.9978
<i>Particle Density at 20°C (g/cm³):</i>	2.73

Trial 2

<i>Weight of pycnometer filled w/air (g):</i>	92.43
<i>Weight of pycnometer filled w/soil (g):</i>	142.75
<i>Weight of pycnometer filled w/soil & water (g):</i>	373.01
<i>Weight of pycnometer filled w/water (g):</i>	341.01
<i>Observed temperature (°C):</i>	29.00
<i>Density of water at observed temperature (g/cm³):</i>	0.9960
<i>Particle Density (g/cm³):</i>	2.74
<i>Correction factor, K:</i>	0.9978
<i>Particle Density at 20°C (g/cm³):</i>	2.74

Average Particle Density (g/cm³): 2.74

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002375



Daniel B. Stephens & Associates, Inc.

Particle Density

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (38.5-39.5)
Ring Number: NA
Depth: NA
Test Date: 17-Feb-03

Trial 1

<i>Weight of pycnometer filled w/air (g):</i>	99.95
<i>Weight of pycnometer filled w/soil (g):</i>	150.48
<i>Weight of pycnometer filled w/soil & water (g):</i>	380.71
<i>Weight of pycnometer filled w/water (g):</i>	348.67
<i>Observed temperature (°C):</i>	29.00
<i>Density of water at observed temperature (g/cm³):</i>	0.9960
<i>Particle Density (g/cm³):</i>	2.72
<i>Correction factor, K:</i>	0.9978
<i>Particle Density at 20°C (g/cm³):</i>	2.73

Trial 2

<i>Weight of pycnometer filled w/air (g):</i>	95.46
<i>Weight of pycnometer filled w/soil (g):</i>	145.91
<i>Weight of pycnometer filled w/soil & water (g):</i>	376.30
<i>Weight of pycnometer filled w/water (g):</i>	344.20
<i>Observed temperature (°C):</i>	29.00
<i>Density of water at observed temperature (g/cm³):</i>	0.9960
<i>Particle Density (g/cm³):</i>	2.74
<i>Correction factor, K:</i>	0.9978
<i>Particle Density at 20°C (g/cm³):</i>	2.74

Average Particle Density (g/cm³): 2.74

Comments:

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002376



Summary of Atterberg Tests

Sample Number	Liquid Limit	Plastic Limit	Plasticity Index	Classification
MW-12 (13.5-14.5)	27.4	23.2	4.2	ML
MW-12 (46-47)	32.4	26.7	5.7	ML
MW-15 (13.5-14.5)	21.4	19.2	2.2	ML
MW-15 (28.5-29.5)	—	—	—	ML
MW-15 (38.5-39.5)	35.9	—	—	ML
MW-16 (13.5-14.5)	29.5	21.6	7.9	CL
MW-16 (23.5-24.5)	—	—	—	ML
MW-16 (28.5-29.5)	37.5	23.9	13.6	CL
MW-16 (38.5-39.5)	—	—	—	ML

— = Soil requires visual-manual classification due to non-plasticity



Daniel B. Stephens & Associates, Inc.

Atterberg Limits

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (13.5-14.5)
Ring Number: NA
Depth: NA

Test Date: 24-Feb-03

Liquid Limit

	Trial 1	Trial 2	Trial 3
<i>Number of drops:</i>	34	27	18
<i>Pan number:</i>	LL2	LL3	LL1
<i>Weight of pan plus moist soil (g):</i>	129.95	130.18	132.48
<i>Weight of pan plus dry soil (g):</i>	126.74	126.90	128.72
<i>Weight of pan (g):</i>	114.87	114.93	115.11
<i>Gravimetric moisture content (% g/g):</i>	27.10	27.38	27.59
<i>Liquid Limit:</i>	27.37		

Plastic Limit

	Trial 1	Trial 2
<i>Pan number:</i>	PL1	PL3
<i>Weight of pan plus moist soil (g):</i>	122.57	122.42
<i>Weight of pan plus dry soil (g):</i>	121.11	121.01
<i>Weight of pan (g):</i>	114.75	114.93
<i>Gravimetric moisture content (% g/g):</i>	23.03	23.30
<i>Plastic Limit:</i>	23.17	

Results

Liquid Limit: 27.37
Plastic Limit: 23.17
Plasticity Index: 4.20
Classification: ML

Comments:

-- = Soil requires visual-manual classification due to non-plasticity

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002378



Daniel B. Stephens & Associates, Inc.

Atterberg Limits

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-12 (46-47)
Ring Number: NA
Depth: NA

Test Date: 24-Feb-03

Liquid Limit

	Trial 1	Trial 2	Trial 3
<i>Number of drops:</i>	32	24	16
<i>Pan number:</i>	LL1	LL2	LL3
<i>Weight of pan plus moist soil (g):</i>	134.11	131.19	132.63
<i>Weight of pan plus dry soil (g):</i>	129.23	126.87	128.20
<i>Weight of pan (g):</i>	113.69	113.66	115.04
<i>Gravimetric moisture content (% g/g):</i>	31.45	32.71	33.71
<i>Liquid Limit:</i>	32.37		

Plastic Limit

	Trial 1	Trial 2
<i>Pan number:</i>	PL1	PL2
<i>Weight of pan plus moist soil (g):</i>	122.07	118.90
<i>Weight of pan plus dry soil (g):</i>	120.61	117.66
<i>Weight of pan (g):</i>	115.14	113.03
<i>Gravimetric moisture content (% g/g):</i>	26.79	26.63
<i>Plastic Limit:</i>	26.71	

Results

Liquid Limit: 32.37
Plastic Limit: 26.71
Plasticity Index: 5.66
Classification: ML

Comments:

--- = Soil requires visual-manual classification due to non-plasticity

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002379



Daniel B. Stephens & Associates, Inc.

Atterberg Limits

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (13.5-14.5)
Ring Number: NA
Depth: NA

Test Date: 24-Feb-03

Liquid Limit

	Trial 1	Trial 2	Trial 3
<i>Number of drops:</i>	33	26	19
<i>Pan number:</i>	LL1	LL2	LL3
<i>Weight of pan plus moist soil (g):</i>	138.16	131.66	133.03
<i>Weight of pan plus dry soil (g):</i>	134.58	128.72	129.39
<i>Weight of pan (g):</i>	117.36	114.75	113.03
<i>Gravimetric moisture content (% g/g):</i>	20.77	21.04	22.26
<i>Liquid Limit:</i>	21.40		

Plastic Limit

	Trial 1	Trial 2
<i>Pan number:</i>	PL1	PL2
<i>Weight of pan plus moist soil (g):</i>	122.61	122.73
<i>Weight of pan plus dry soil (g):</i>	121.17	121.47
<i>Weight of pan (g):</i>	113.66	114.93
<i>Gravimetric moisture content (% g/g):</i>	19.11	19.23
<i>Plastic Limit:</i>	19.17	

Results

Liquid Limit: 21.40
Plastic Limit: 19.17
Plasticity Index: 2.23
Classification: ML

Comments:

--- = Soil requires visual-manual classification due to non-plasticity

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002380



Daniel B. Stephens & Associates, Inc.

Atterberg Limits

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (28.5-29.5)
Ring Number: NA
Depth: NA

Test Date: 24-Feb-03

Liquid Limit

	Trial 1	Trial 2	Trial 3
Number of drops:			
Pan number:			
Weight of pan plus moist soil (g):			
Weight of pan plus dry soil (g):			
Weight of pan (g):			
Gravimetric moisture content (% g/g):	---	---	---
Liquid Limit:	---		

Plastic Limit

	Trial 1	Trial 2
Pan number:		
Weight of pan plus moist soil (g):		
Weight of pan plus dry soil (g):		
Weight of pan (g):		
Gravimetric moisture content (% g/g):	---	---
Plastic Limit:	---	

Results

Liquid Limit: ---
Plastic Limit: ---
Plasticity Index: ---
Classification (Visual Method): ML

Comments:

--- = Soil requires visual-manual classification due to non-plasticity

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002381



Daniel B. Stephens & Associates, Inc.

Atterberg Limits

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-15 (38.5-39.5)
Ring Number: NA
Depth: NA

Test Date: 24-Feb-03

Liquid Limit

	Trial 1	Trial 2	Trial 3
Number of drops:	32	26	17
Pan number:	LL1	LL2	LL3
Weight of pan plus moist soil (g):	143.03	138.05	134.86
Weight of pan plus dry soil (g):	135.54	129.61	129.44
Weight of pan (g):	114.18	111.57	114.87
Gravimetric moisture content (% g/g):	35.08	35.72	37.24
Liquid Limit:	35.90		

Plastic Limit

	Trial 1	Trial 2
Pan number:		
Weight of pan plus moist soil (g):		
Weight of pan plus dry soil (g):		
Weight of pan (g):		
Gravimetric moisture content (% g/g):	---	---
Plastic Limit:	---	

Results

Liquid Limit: 35.90
Plastic Limit: ---
Plasticity Index: ---
Classification (Visual Method): ML

Comments:

--- = Soil requires visual-manual classification due to non-plasticity

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002382



Daniel B. Stephens & Associates, Inc.

Atterberg Limits

Job Name: Shaw Environmental
Job Number: WVR03.0011.00
Sample Number: MW-16 (13.5-14.5)
Ring Number: NA
Depth: NA

Test Date: 24-Feb-03

Liquid Limit

	Trial 1	Trial 2	Trial 3
Number of drops:	35	28	19
Pan number:	LL1	LL2	LL3
Weight of pan plus moist soil (g):	126.05	138.18	135.12
Weight of pan plus dry soil (g):	123.34	133.49	130.11
Weight of pan (g):	113.64	117.40	113.69
Gravimetric moisture content (% g/g):	27.96	29.17	30.53
Liquid Limit:	29.46		

Plastic Limit

	Trial 1	Trial 2
Pan number:	PL1	PL2
Weight of pan plus moist soil (g):	118.74	120.76
Weight of pan plus dry soil (g):	117.89	119.75
Weight of pan (g):	113.91	115.11
Gravimetric moisture content (% g/g):	21.51	21.69
Plastic Limit:	21.60	

Results

Liquid Limit: 29.46
Plastic Limit: 21.60
Plasticity Index: 7.86
Classification: CL

Comments:

-- = Soil requires visual-manual classification due to non-plasticity

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002383



Daniel B. Stephens & Associates, Inc.

Atterberg Limits

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (23.5-24.5)
Ring Number: NA
Depth: NA

Test Date: 20-Feb-03

Liquid Limit

	Trial 1	Trial 2	Trial 3
Number of drops:			
Pan number:			
Weight of pan plus moist soil (g):			
Weight of pan plus dry soil (g):			
Weight of pan (g):			
Gravimetric moisture content (% g/g):	---	---	---
Liquid Limit:	---		

Plastic Limit

	Trial 1	Trial 2
Pan number:		
Weight of pan plus moist soil (g):		
Weight of pan plus dry soil (g):		
Weight of pan (g):		
Gravimetric moisture content (% g/g):	---	---
Plastic Limit:	---	

Results

Liquid Limit: ---
Plastic Limit: ---
Plasticity Index: ---
Classification (Visual Method): ML

Comments:

--- = Soil requires visual-manual classification due to non-plasticity

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002384



Atterberg Limits

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (28.5-29.5)
Ring Number: NA
Depth: NA

Test Date: 26-Feb-03

Liquid Limit

	Trial 1	Trial 2	Trial 3
Number of drops:	34	23	17
Pan number:	LL1	LL2	LL3
Weight of pan plus moist soil (g):	131.38	131.35	138.44
Weight of pan plus dry soil (g):	126.98	127.18	131.72
Weight of pan (g):	114.96	116.07	114.49
Gravimetric moisture content (% g/g):	36.63	37.44	38.99
Liquid Limit:	37.51		

Plastic Limit

	Trial 1	Trial 2
Pan number:	PL2	PL3
Weight of pan plus moist soil (g):	123.67	128.78
Weight of pan plus dry soil (g):	122.01	127.37
Weight of pan (g):	115.04	121.47
Gravimetric moisture content (% g/g):	23.87	23.99
Plastic Limit:	23.93	

Results

Liquid Limit: 37.51
Plastic Limit: 23.93
Plasticity Index: 13.58
Classification: CL

Comments:

--- = Soil requires visual-manual classification due to non-plasticity

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd



Daniel B. Stephens & Associates, Inc.

Atterberg Limits

Job Name: Shaw Environmental
Job Number: WR03.0011.00
Sample Number: MW-16 (38.5-39.5)
Ring Number: NA
Depth: NA

Test Date: 26-Feb-03

Liquid Limit

	Trial 1	Trial 2	Trial 3
Number of drops:			
Pan number:			
Weight of pan plus moist soil (g):			
Weight of pan plus dry soil (g)			
Weight of pan (g):			
Gravimetric moisture content (% g/g):	---	---	---
Liquid Limit:	---		

Plastic Limit

	Trial 1	Trial 2
Pan number:		
Weight of pan plus moist soil (g):		
Weight of pan plus dry soil (g)		
Weight of pan (g):		
Gravimetric moisture content (% g/g):	---	---
Plastic Limit:	---	

Results

Liquid Limit: ---
Plastic Limit: ---
Plasticity Index: ---
Classification (Visual Method): ML

Comments:

--- = Soil requires visual-manual classification due to non-plasticity

Laboratory analysis by: D. O'Dowd
Data entered by: D. O'Dowd
Checked by: D. O'Dowd

LEU 002386



Summary of Fraction Organic Carbon Tests

<u>Sample Number</u>	<u>Fraction Organic Carbon (%)</u>
MW-12 (13.5-14.5)	ND
MW-12 (21-22)	ND
MW-12 (31-32)	0.14
MW-12 (46-47)	0.13
MW-15 (13.5-14.5)	0.12
MW-15 (23.5-24.5)	0.14
MW-15 (28.5-29.5)	0.13
MW-15 (38.5-39.5)	0.12
MW-16 (13.5-14.5)	0.19
MW-16 (23.5-24.5)	0.12
MW-16 (28.5-29.5)	0.18
MW-16 (38.5-39.5)	0.14

ND-Not detected at the reporting limit

Analysis provided by Hall Environmental, Albuquerque, NM.

Hall Environmental Analysis Laboratory

Date: 03-Mar-03

CLIENT: Daniel B. Stephens & Assoc. **Lab Order:** 0302172
Project: DBS & A

Lab ID: 0302172-01 **Collection Date:** 2/27/2003 2:00:00 PM
Client Sample ID: MW-12 (13.5-14.5) **Matrix:** SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
----------	--------	-------	------	-------	----	---------------

TOC BY WALKLEY BLACK						Analyst: HVA
TOC	ND	0.10		% C	1	2/28/2003

Lab ID: 0302172-02 **Collection Date:** 2/27/2003 2:00:00 PM
Client Sample ID: MW-12 (21-22) **Matrix:** SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
----------	--------	-------	------	-------	----	---------------

TOC BY WALKLEY BLACK						Analyst: HVA
TOC	ND	0.10		% C	1	2/28/2003

Lab ID: 0302172-03 **Collection Date:** 2/27/2003 2:00:00 PM
Client Sample ID: MW-12 (31-32) **Matrix:** SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
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TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.14	0.10		% C	1	2/28/2003

Lab ID: 0302172-04 **Collection Date:** 2/27/2003 2:00:00 PM
Client Sample ID: MW-12 (46-47) **Matrix:** SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
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TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.13	0.10		% C	1	2/28/2003

Lab ID: 0302172-05 **Collection Date:** 2/27/2003 2:00:00 PM
Client Sample ID: MW-15 (13.5-14.5) **Matrix:** SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
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TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.12	0.10		% C	1	2/28/2003

Lab ID: 0302172-06 **Collection Date:** 2/27/2003 2:00:00 PM
Client Sample ID: MW-15 (23.5-24.5) **Matrix:** SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
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TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.14	0.10		% C	1	2/28/2003

Qualifiers: ND - Not Detected at the Reporting Limit
J - Analyte detected below quantitation limits
B - Analyte detected in the associated Method Blank
* - Value exceeds Maximum Contaminant Level

S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits
E - Value above quantitation range

LEU 002388

Hall Environmental Analysis Laboratory

Date: 03-Mar-03

CLIENT: Daniel B. Stephens & Assoc.
Project: DBS & A

Lab Order: 0302172

Lab ID: 0302172-07 Collection Date: 2/27/2003 2:00:00 PM
Client Sample ID: MW-15 (28.5-29.5) Matrix: SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
----------	--------	-------	------	-------	----	---------------

TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.13	0.10		% C	1	2/28/2003

Lab ID: 0302172-08 Collection Date: 2/27/2003 2:00:00 PM
Client Sample ID: MW-15 (38.5-39.5) Matrix: SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
----------	--------	-------	------	-------	----	---------------

TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.12	0.10		% C	1	2/28/2003

Lab ID: 0302172-09 Collection Date: 2/27/2003 2:00:00 PM
Client Sample ID: MW-16 (13.5-14.5) Matrix: SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
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TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.19	0.10		% C	1	2/28/2003

Lab ID: 0302172-10 Collection Date: 2/27/2003 2:00:00 PM
Client Sample ID: MW-16 (23.5-24.5) Matrix: SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
----------	--------	-------	------	-------	----	---------------

TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.12	0.10		% C	1	2/28/2003

Lab ID: 0302172-11 Collection Date: 2/27/2003 2:00:00 PM
Client Sample ID: MW-16 (28.5-29.5) Matrix: SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
----------	--------	-------	------	-------	----	---------------

TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.18	0.10		% C	1	2/28/2003

Lab ID: 0302172-12 Collection Date: 2/27/2003 2:00:00 PM
Client Sample ID: MW-16 (38.5-39.5) Matrix: SOIL

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
----------	--------	-------	------	-------	----	---------------

TOC BY WALKLEY BLACK						Analyst: HVA
TOC	0.14	0.10		% C	1	2/28/2003

Qualifiers: ND - Not Detected at the Reporting Limit
J - Analyte detected below quantitation limits
B - Analyte detected in the associated Method Blank
* - Value exceeds Maximum Contaminant Level

S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits
E - Value above quantitation range

Hall Environmental Analysis Laboratory

Date: 03-Mar-03

CLIENT: Daniel B. Stephens & Assoc.

Work Order: 0302172

Project: DBS & A

QC SUMMARY REPORT

Method Blank

Sample ID	MBLK	Batch ID:	R7488	Test Code:	Walkley Bloc	Units:	% C	Analysis Date	2/28/2003	Prep Date			
Client ID:		Run ID:	WC_030228E	SeqNo:	170278								
Analyte		Result		PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	RPD Ref Val	%RPD	RPDLimit	Qual
TOC		ND		0.10									

Qualifiers: ND - Not Detected at the Reporting Limit
J - Analyte detected below quantitation limits

S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits

B - Analyte detected in the associated Method Blank

/

Hall Environmental Analysis Laboratory

Date: 03-Mar-03

CLIENT: Daniel B. Stephens & Assoc.
Work Order: 0302172
Project: DBS & A

QC SUMMARY REPORT

Sample Duplicate

Sample ID	0302172-01A	Batch ID:	R7448	Test Code:	Walkley Bloc	Units:	% C	Analysis Date	2/28/2003	Prep Date		
Client ID:	MW-12 (13.5-14.5)	Run ID:	WC_030228E	SeqNo:	170281							
Analyte		Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	RPD Ref Val	%RPD	RPDLimit	Qual
TOC		ND	0.10	0	0	0	0	0	0	0	20	

Sample ID	0302172-10A	Batch ID:	R7448	Test Code:	Walkley Bloc	Units:	% C	Analysis Date	2/28/2003	Prep Date		
Client ID:	MW-16 (23.5-24.5)	Run ID:	WC_030228E	SeqNo:	170291							
Analyte		Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	RPD Ref Val	%RPD	RPDLimit	Qual
TOC		0.127	0.10	0	0	0	0	0	0.116	9.05	20	

Qualifiers: ND - Not Detected at the Reporting Limit
I - Analyte detected below quantitation limits

S - Spike Recovery outside accepted recovery limits
R - RPD outside accepted recovery limits

B - Analyte detected in the associated Method Blank

LEU 002391

Hall Environmental Analysis Laboratory

Date: 03-Mar-03

CLIENT: Daniel B. Stephens & Assoc.
Work Order: 0302172
Project: DBS & A

QC SUMMARY REPORT
Laboratory Control Spike - generic

Sample ID	LCS #1	Batch ID:	R7488	Test Code:	Walkley Bloc	Units:	% C	Analysis Date	2/28/2003	Prep Date		
Client ID:		Run ID:	WC_030228E	SeqNo:	170279							
Analyte		Result	PQL	SPK value	SPK Ref Val	%REC	LowLimit	HighLimit	RPD Ref Val	%RPD	RPDLimit	Qual
TOC		2.838	0.10	2.6	0	109	80	120	0			

Qualifiers:

ND - Not Detected at the Reporting Limit

J - Analyte detected below quantitation limits

S - Spike Recovery outside accepted recovery limits

R - RPD outside accepted recovery limits

B - Analyte detected in the associated Method Blank

1

LEU 002392

Boring / Well Log

Field Supervisor: J. Jazmin

Sheet 1 of 1

Project: Former Angeles Chemical
 Drilling Company: Layne
 Date Drilled: 06-07-02

Well Number: MW-9

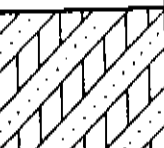
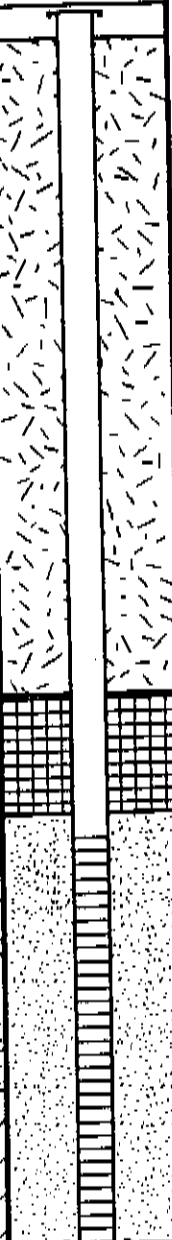
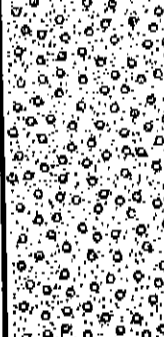

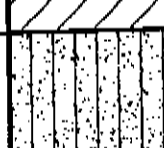
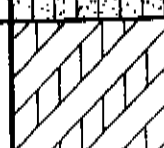
Boring Method: Hollow Stem Auger

Bore Hole Depth: 50'

Water Depth: 31'

Start Time: 0815 Hrs

Finish Time: 0950 Hrs

Depth (feet)	Blow Counts	Sample Number	Organic Vapor (ppm)	Sample Description	Graphic Log	Well Construction
0			10	CL/ML - SILTY, CLAYEY SAND, BROWN, W/ MOISTURE, NO ODOR		
5			3.5	CL/ML - SILTY, CLAYEY SAND, BROWN, W/ MOISTURE, NO ODOR		
10			23	CL/ML - SILTY, CLAY, REDDISH BROWN, W/ MOISTURE, NO ODOR		
15			1	SW - SAND, FINE TO COARSE, W/ GRAVEL, W/ MOISTURE, NO ODOR		
17.5			4.2	SW - SAND, COARSE, W/ GRAVEL, BROWN, DRY, NO ODOR		
20			6.4	SW - SAND, FINE TO COARSE, W/ GRAVEL, LIGHT BROWN, DRY, NO ODOR		
25			62.6	CL - CLAY, BROWN, W/ MOISTURE, NO ODOR		
29			62.4	CL - CLAY, BROWN, STIFF, W/ MOISTURE, NO ODOR		
30			64	SF/ML - SILTY SAND, BROWN, W/ MOISTURE, NO ODOR		
35			1	CL/ML - SILTY CLAY, BROWN, W/ MOISTURE, NO ODOR		
40			1.2	CL/ML - SILTY CLAY, BROWN, W/ MOISTURE, STIFF, NO ODOR		
45						END CAP
50						

LEI 002202

Black Environmental Investigations, Inc.



Drilling Log

Monitoring Well **MW-11**

Page: 1 of 3

Project Angeles Chemical Owner Angeles Chemical
Location Santa Fe Springs, California Proj. No. 838920
Surface Elev. 149.4 ft Total Hole Depth 40.0 ft North 1807439.71 ft East 6542496.73 ft
Top of Casing 149.12 ft Water Level Initial 31.0 ft Static 32.6 ft Diameter 8 in.
Screen: Dia 2 in. Length 10 ft Type/Size PVC 0.020 in.
Casing: Dia 2 in. Length 30 ft Type PVC
Fill Material 53 Sand (20-40) bentonite chips (25-28) Rig/Core GME 85/Continuous Core
Drill Co. Layne Method Hollow Stem Auger
Driller Ruben Log By Chris Rohling Date 11/14/02 Permit # NA
Checked By _____ License No. RQ 97229

COMMENTS

ND = None Detected
NA = Not Applicable

No samples collected from surface to 27.6 feet below grade surface due to proximity of boring BSB-7.

DRAFT

Depth (ft.)	Well Completion	PID (ppm)	Sample ID & Recovery	Blow Count Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.	Elevation (ft.)
0								149.41
2							See comment above.	148
4								148
6								144
8						SM		142
10								140
12								138
14								136

Continued Next Page

SHAW COMMERCIAL Rev: 8/12/02 ANGELES.GPJ IT CORP.GDT 1/30/03

LEU 002394



Drilling Log

Monitoring Well **MW-11**

Page: 2 of 3

Project Angeles Chemical Owner Angeles Chemical
Location Santa Fe Springs, California Proj. No. 838920

Depth (ft.)	Well Completion	PID (ppm)	Sample ID % Recovery	Blow Count Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.	Elevation (ft.)
14							Continued	134
16								132
18								130
20								128
22						SM		126
24							SILTY SAND with gravel: Approximately 60% sand, 30% silt and 10% gravel. Sand is fine (25%) to medium (35%), subangular to subrounded and micaceous. Silt is non-plastic with low toughness. Gravel is fine and subangular to rounded with quartz fragments. Dark greenish gray (5G, 4/1) to black (N2.5), moist with a strong chemical odor.	124
26								122
28							Well defined contact SILTY SAND: Approximately 60% sand and 30% silt. Sand is fine and subangular to rounded with abundant quartz clasts. Silt is non-plastic with low toughness. Dark grayish brown (2.5Y, 4/2), dry with a strong chemical odor.	120
30			100%					
32			100%			SP	Gradual gradation Grades to poorly graded SAND: Approximately 40% fine sand and 60% medium sand. Sand is subangular to subrounded, uniform, well sorted, contains abundant quartz clasts. Dark bluish gray (5B, 4/1) and saturated with a strong chemical odor.	118

Continued Next Page

LEU 002395



Drilling Log

Monitoring Well

MW-11

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Project Angeles Chemical

Owner Angeles Chemical

Location Santa Fe Springs, California

Proj. No. 838920

Depth (ft.)	Well Completion	PID (ppm)	Sample ID % Recovery	Blow Count Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.	Elevation (ft.)
							Continued	
34			100%			SP		116
36			100%			SP		114
38								112
40			100%			ML	Well defined contact SANDY SILT: Approximately 70% silt and 30% sand. Silt is low plasticity, low toughness, low dry strength and rapid dilatancy. Sand is fine, subangular to subrounded and micaceous. Dark grayish brown (2.5Y, 4/2), dry, faint chemical odor, low energy depositional environment, possibly a vertical retarding unit.	110
							End of exploration at 40 feet below grade surface.	108
42								108
44								106
46								104
48								102
50								100

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APPENDIX B
AIR SPARGING PILOT TEST CHECKLIST

AIR SPARGING PILOT TEST CHECKLIST

Activity	Question(s) Answered	Site- Specific Pilot Test Approach	Comments
Baseline sampling	What are aquifer conditions prior to air sparging startup?	X	<ul style="list-style-type: none"> It is important to establish baseline measurements for several key parameters in order to measure the effectiveness of the air sparging system. Methods for collecting dissolved oxygen measurements; pressure transducer measurements; and VOC, and carbon dioxide measurements are described in Appendix B of the Design Paradigm (Leeson et al., 2001).
	Dissolved Oxygen	X	<ul style="list-style-type: none"> Conduct baseline dissolved oxygen measurements.
	Pressure transducer data	X	<ul style="list-style-type: none"> Pressure data should be collected for a long enough period to assess diurnal changes in water level (e.g., tidal fluctuations) if they are believed to be significant.
	VOCs, O ₂ , and CO ₂ concentrations	X	<ul style="list-style-type: none"> Soil vapor concentrations (including VOCs, O₂, and CO₂ concentrations) should be measured prior to air sparging startup. This provides initial contaminant mass estimates and a measure of microbial activity in the vadose zone.
	Initial SVE off-gas contaminant concentrations	X	<ul style="list-style-type: none"> If SVE will be utilized during pilot testing, conduct off-gas sampling and analysis; The SVE system should be operated prior to air sparging startup. This (1) verifies proper system operation and (2) establishes VOC volatilization rates from the vadose zone versus the saturated zone.
Injection pressure and flowrate test	Is it possible to achieve desired flowrate at reasonable pressures?	X	<ul style="list-style-type: none"> Injection pressures should be recorded at three flowrates: 5, 10, and 20 cfm. The air injection pressure is recorded at the onset of flow as well as every 5 to 10 minutes until the pressure and flow stabilize. If a flowrate of at least 5 cfm cannot be achieved without exceeding a safe pressure, air sparging is not feasible at this site. The operating pressure is determined by the depth of the air sparging well below the water table and the permeability of the aquifer. The pressure at which fracturing of the aquifer may occur can be estimated by: $P_{fracture} [psig] = 0.73 * D_{soil}$ where: D [ft] = depth below ground surface to the top of the air injection well screened interval. Pressures in excess of P_{fracture} can cause fracturing of the formation; however, as the pressure drops off rapidly away from an injection point, the extent of fracturing in most cases is expected to be limited to the area immediately surrounding the well.

AIR SPARGING PILOT TEST CHECKLIST

Groundwater pressure response test	<p>What are the general characteristics of the air distribution?</p> <p>a) Semiconical air distribution in a homogenous setting OR</p> <p>b) Irregular shape due to significant stratification.</p>	X	<ul style="list-style-type: none"> • The primary objective of this test is to assess the time required for airflow distribution to come to steady state. • Typically, as long as the volume of air below the water table is increasing, the groundwater pressure will remain above pre-air sparging levels. As a result, the time required for groundwater pressure to return to pre-air sparging values is a good measure of the time required for the macro-scale air distribution to come to steady state. • For homogeneous media (e.g., uniform sands), the time required for air sparging pressures to return to pre-air sparging values will generally be measured in tens of minutes to a few hours. If the site is stratified with lower-permeability layers, then the groundwater pressure may remain elevated for tens of hours to days. • Generally, at sites where groundwater pressures remain elevated by more than a few tens of centimeters for more than 8 hours, it can be assumed that the air distribution is controlled to a high degree by the structure of the aquifer. It will be important to determine if the air is being delivered to the treatment area in an effective manner.
Helium tracer test	<p>What is the lateral extent of the air distribution?</p> <p>Are there indications of preferential flowpaths?</p>	X	<ul style="list-style-type: none"> • Helium can be used in two primary ways as a tracer for air sparging systems (Leeson et al., 2001). In both tests, a rechargeable helium leak detector is used to detect helium at concentrations from 0.01 to 100 percent. • To characterize the injected air distribution pattern in the subsurface, helium is added to the sparge air at a known rate to achieve a steady helium concentration of about 2 to 10% by volume. Immediately after helium injection, until 20 minutes have lapsed, all of the vadose zone monitoring points and groundwater monitoring wells are monitored for helium. The helium measurements show which portion of the saturated zone is coming into contact with the injected air. • To assess the effectiveness of the SVE system in capturing the injected air, helium is added into the sparge air at a known rate and the SVE off-gas is monitored for the appearance of helium. Injection should continue until a stable helium concentration is achieved. The fraction of helium recovered by the SVE system is calculated. • Helium recovery data tends to fall into two ranges. The sparge air either makes it to the vadose zone and is collected by the SVE system with a high (e.g., >70%) recovery, or the air is stratigraphically trapped, pushing it beyond the SVE system or out monitoring wells, in which case recovery is low (e.g., <20%).

AIR SPARGING PILOT TEST CHECKLIST

SVE offgas sampling	What is the volatilization rate?	X	<ul style="list-style-type: none">• With an SVE system, increases in contaminant concentrations in the SVE off-gas, and the SVE extraction flowrate can be used to estimate the mass removal rate.
	Are there any obvious safety hazards?		<ul style="list-style-type: none">• Measurements made during the short duration of a pilot test are not indicative of long-term performance. However, it can generally be assumed that the pilot test data represent the maximum removal rate from the system (pre-optimization). In that context, if mass removal rates during the pilot test are very low, then there should be significant concern about the viability of air sparging at the site.
Dissolved oxygen (DO) measurements	What is the approximate lateral extent of the air distribution?	X	<ul style="list-style-type: none">• If the preliminary measurements show low DO concentrations (e.g., less than 2 mg/L), it may be possible to identify areas where air sparging has resulted in increases in DO. To determine this, dissolved oxygen should be measured in all groundwater monitoring points immediately following the pilot test.
	Are there indications of preferred directions?		<ul style="list-style-type: none">• At many sites where active biodegradation is ongoing, there may be significant quantities of reduced species (e.g., Fe(2+)) which act as rapid sinks for oxygen and masks the delivery of oxygen to that region.
			<ul style="list-style-type: none">• Microbial consumption of oxygen can be very high, resulting in oxygen being consumed as rapidly as it reaches an area, and therefore cannot be detected with instrumentation.
			<ul style="list-style-type: none">• Care must be taken to avoid artifacts caused by air entry into monitoring wells and preferential aeration within the well (Johnson et al., 1997).
Other observations	Are there any odors, noise, or other factors present that make system operation less acceptable?	X	<ul style="list-style-type: none">• It is important to note any qualitative indicators of air distribution, such as bubbling or gurgling noises in wells, water "fountaining" out of monitoring points, etc.
			<ul style="list-style-type: none">• It is also important to be aware of odors due to the contaminants, noise due to the equipment, or other environmental factors.
			<ul style="list-style-type: none">• These factors may not make air sparging infeasible from a technical standpoint, but may make the system less acceptable for the community.

AIR SPARGING PILOT TEST CHECKLIST

SF6 distribution test	What is the vertical and lateral extent of the air distribution in the target treatment zone? What are the oxygen transfer rates to groundwater?	X	<ul style="list-style-type: none">SF6 is used as a tracer that mimics oxygen to determine the distribution of air in the groundwater (Johnson et al., 1996).
			<ul style="list-style-type: none">SF6 has a water solubility that is similar to oxygen; however, SF6 has several advantages over oxygen and as a result the test can be both more sensitive and more quantitative.
			<ul style="list-style-type: none">SF6 is blended with the injection air stream at a known concentration for a period of 12 to 24 hours. At the end of the SF6 injection period, groundwater samples are collected and analyzed for SF6. The duration of SF6 injection and the cumulative volume of groundwater sample are recorded. Based on the concentration of SF6 in the injected air, and the Henry's law constant for SF6, the percent saturation of SF6 in the groundwater sample can be determined.
			<ul style="list-style-type: none">In general, the results can be divided into three groups: (a) values approaching saturation (e.g., >40% of theoretical solubility) indicate that the sample location lies within the "zone of aeration" of the air sparging system; (b) samples with low concentrations of SF6 (e.g., <10%) indicate that an air channel may be in the vicinity of the sampling location (e.g., it may be within the "zone of treatment") but the air saturation in the aquifer at that point is probably low; and (c) samples that have no SF6 present are presumed to lie outside both the aeration and treatment zones.

Checklist based on Matrix provided in Appendix G of "AIR SPARGING GUIDANCE DOCUMENT", NFESC Technical Report TR-2193-ENV, Battelle, August 31, 2001

APPENDIX C

PROCEDURES FOR CONDUCTING HELIUM TRACER TESTS TO EVALUATE RECOVER OF INJECTED AIR DURING AIR SPARGING PILOT TEST

Procedures for Conducting Helium Tracer Tests to Evaluate Recovery of Injected Air During Air Sparging Pilot Test

1. Introduction

a. Introduction to In Situ Air Sparging (IAS)

Air Sparging (AS) is a groundwater remediation technique in which air is injected directly into a water saturated medium to remove contaminants by volatilization and to enhance aerobic degradation. AS is used both to remediate aqueous groundwater plumes and to treat sources which contain nonaqueous-phase liquids (NAPLs).

The setup of an AS remediation system is shown schematically in **Figures 5-2 through 5-8**. It generally consists of one or more air injection wells and one or more SVE wells. As mentioned above, the primary purposes of the injection well(s) are to volatilize contaminants and to increase aerobic biodegradation by introducing additional oxygen into the groundwater. These wells are usually designed in a manner similar to groundwater monitoring wells, except that they generally have short screens (i.e., 1 to 2 ft) and are screened entirely below the water table.

The principal purpose of the extraction wells is to prevent the off-site migration of vapors volatilized by the IAS system. Generally, the setup of the extraction wells is similar to conventional soil vapor extraction (SVE) systems. This often will include an air blower, a "knockout" drum for removing liquids, and an off-gas treatment system.

The equipment required for the IAS portion of the system is minimal. In addition to the injection well, all that is generally required is a compressor capable of delivering air at the desired flow rate at a pressure governed by the depth of injection. It is also desirable to be able to measure and control air flow and pressure at the injection well.

b. Introduction to Air Recovery Tests

Air recovery tests are an important means of evaluating the performance of SVE systems for capturing air injected below the water table as part of an IAS remediation system. The recovery tests are important because they provide direct evidence of the extent to which injected air may be moving off site. Off-site migration is potentially important because it is a means by which potentially hazardous concentrations of contaminants can be carried to adjacent properties.

2. Test Objective

a. General Comments

In order to prevent off-site migration of vapors during AS, combined IAS/SVE systems are often designed in such a way that extracted air flow exceeds air injection by some multiplicative factor (e.g., 5X). In addition, to demonstrate that the design is working, soil gas vacuum surveys in the vicinity of the IAS/SVE system are usually conducted. It is generally concluded that if no pressures greater than ambient are observed, all of the AS air is being captured by the SVE system. However, it is generally difficult to relate vacuum data to recovery of AS air. This is the case because numerous potential air flow patterns in the groundwater zone can exist. For example, if AS air is injected into sand below a continuous clay layer, the air may move laterally beyond the radius of influence of the SVE well before it has the opportunity to reach the water table. In this case, the sparge air might not be captured by the SVE system.

The previous example implies that under some circumstances pressure measurements alone will not conclusively demonstrate that IAS air is being captured. As a consequence, it is important to conduct tests which can unambiguously determine if all of the AS air is being captured by the SVE system.

b. Primary Objective

The primary objective of helium recovery tracer tests described here is to unambiguously determine the recovery efficiency of air injected during AS.

3. Theory

a. Underlying Principal

The principal underlying the helium recovery tests is simple. Helium is injected into the subsurface at a known rate and the rate of helium recovery at the SVE is calculated from the observed helium concentration in the SVE effluent and the SVE flow rate.

b. Practical Considerations

In order to successfully conduct a helium tracer test, it is necessary to accurately measure flow rates and helium concentrations. As a result, calibration of the analytical equipment (both flow meters and the helium detector) is extremely important. It is also very important to have a system which is free of leaks. This means not only the injection and extraction systems, but also the sampling and analysis systems.

c. Steps in Conducting a Helium Recovery Test

There are four steps in conducting the helium recovery test. They are:

1. Determination of the "100 percent recovery" concentration

Helium is injected at a known rate (the same rate used in the tracer test) directly into the extraction manifold prior to the helium detector. The concentration measured at the helium detector is the 100 percent recovery concentration.

2. Injection of the helium tracer

Once the 100 percent recovery concentration is determined, helium injection into the sparge air can be initiated. This injection rate must be the same as the rate used to determine the 100 percent recovery concentration.

3. Measurement of the helium concentration in the SVE off-gas.

Once helium injection in the sparge air has been initiated, air samples are collected from the extraction manifold at regular intervals until the helium concentration in the effluent stabilizes.

4. Plotting of percent helium recovered as a function of time.

Observed helium concentrations divided by the 100 percent recovery concentration times 100 are plotted as a function of time since the initiation of helium injection. The final values represent the fraction of the injected helium which is recovered by the SVE system.

4. Test Equipment

a. Overview of Experimental Setup

In order to simplify interpretation, the tests should be conducted by injection of helium into a single AS well and recovery from a single SVE well. In nearly all cases, tracer tests will be conducted in conjunction with vapor extraction and injection operations. In that context, the design and installation of the extraction/injection wells will be dictated by the remediation design.

b. Calibration of Analytical Equipment Calibration of the Helium Detector

Helium in the extracted air will be measured with a Mark Products helium detector Model 9822 or equivalent with a minimum sensitivity of 100 ppm (0.01 percent).

The helium detector should be turned on and equilibrated for at least 10 minutes prior to conducting a calibration or obtaining measurements. As part of the calibration process, the internal sampling pump of the helium detector should be checked prior to operation to ensure that it is functioning.

The helium detector should be calibrated each day using helium calibration standards in air. These standards should be pressurized cylinders of 10, 1.0, 0.1, and 0.01 percent helium in air. The instrument is calibrated by connecting it to one of the pressurized

standards and adjusting the flow from the cylinder such that some flow comes out of the vent line. Flow should continue until a stable reading is achieved on the meter (~30 seconds).

Once measurements have been made for each concentration, a calibration curve can be constructed. If any measured value differs from the reported standard value by greater than 20 percent, that standard should be reanalyzed. If the value fails to agree upon reanalysis, the source of the problem should be identified.

Helium standards can be purchased from a specialty gas supplier or they can be prepared on a pressure or volume basis. The pressure-based approach will be discussed here. In general, standards should be prepared in canisters which can withstand 10 atmospheres of pressure and which do not affect the quality of the standard. The final pressure of the standards described here will be 9 atm gauge pressure, which corresponds to a 10-fold dilution of the concentration of helium added to the canister. Preparation of standards can begin with canisters filled with helium-free air at a pressure equal to atmospheric. Standards should be prepared using good-quality pressure gauges which are calibrated against a reference. Water or mercury manometers are excellent references. The canister should be connected to a helium source—either 100 percent helium or a certified mixture (e.g., 1 percent He in air) and a Magnehelic™ gauge. Helium is allowed to flow into the canister until the pressure rises to a predetermined gauge pressure. Typical values are listed in Table B-1. The canister can then be brought to a final pressure of 9 atmospheres.

Table B-1. Typical Pressure Values Used in Preparing Helium Standards

Final Concentration (%)	Stock Concentration (%)	Final Pressure of Stock in Standard Canister (atm)
90	100	9
10	100	1
0.9	1	9
0.1	1	1
0.01	1	0.1

c. Calibration of the Air Flow Meters

Flow rates for the SVE system will generally be in the 10- to 200-scfm range. Vacuum levels will be at 10 to 200 inches of water below ambient pressure. At these high flow rates, a large dry gas meter will be required. If a large dry gas meter is not available, an alternate approach is to use another calibrated flow meter to calibrate the one to be used at the site. Actual versus observed flow rates should be determined over the range of the flow meter at several vacuums between 0 and 0.9 atmosphere. Those data should be plotted as a family of curves with each line corresponding to a different vacuum value.

Flow rates for the IAS system will generally be less than those used for the extraction system. However, pressures will be above atmospheric, rather than below. Flow rates for tracer injection will be in the range of 0.1 to 1 L/min.

d. Calibration of the Sampling Pump

Under many operating conditions the SVE manifold will be under sufficient vacuum that automated analytical equipment will not be able to draw an adequate sample from the manifold. In these cases it will be necessary to use a good quality vacuum pump to draw samples from the manifold and deliver them to the automated analytical equipment. In the context of tracer tests, two potential problems arise with respect to the vacuum pump. First, the pump must be able to move sufficient volumes of air to meet the needs of the analytical equipment, and second the pump should not AS air which can provide additional dilution of the sample stream. The procedures below describe how pump performance can be measured.

Prior to selecting a sampling pump, check the specifications of any automated sampling equipment to be used to determine the volumes of air required by each. (The Mark Products helium detector requires ~100 mL/min.) The first step is to connect the pump to be tested to the apparatus. If two dry test meters are not available, two calibrated flow meters of the appropriate ranges can be used. Then turn on the pump and open the valve so that no vacuum is observed on the gauge. Determine the flow into and out of the pump by recording the volume of flow that occurs in 1 minute on each of the dry test meters or the flow rates on the flow meters. Partially close the valve to produce a vacuum of 5 inches of mercury, and determine the flow rates into and out of the pump.

Repeat the previous procedure with vacuums of 10, 15, 20 and 25 inches of mercury. Prepare a plot of flow rate in and out vs. vacuum. Based on those data, determine the maximum vacuum that provides sufficient flow for the helium detector. Next, determine the sampling pump leak ratio as a function of vacuum. Determine if the leakage of the sampling pump is acceptable (e.g., inflow rate is within a factor of two of outflow rate).

5. Test Procedures

a. Overview of Experimental Procedures

Experimental activities can be divided into the following components. Each is described briefly in the following sections.

1. Determination of the "100 percent recovery" concentration
2. Injection of helium into an AS point
3. Collection of samples from SVE off-gas
4. Determination of recovery rate (percent) of helium

b. Determination of "100 Percent Recovery" Concentration

It is necessary to determine the concentration of helium in the off-gas which represents the concentration at "100 percent recovery" of helium. To do this, helium is injected into the extraction manifold prior to the sample pump at a rate which is the same as will be used for the recovery test. The steps involved in determining the "100 percent recovery" concentration are:

1. Estimate the SVE flow for preliminary calculations (e.g., use the flow meter reading).
2. Calculate the inflow rate of 100 percent helium to produce 1 percent concentration in the effluent (See Example Calculation A-1).
3. Install a good vacuum pump (metal bellows or diaphragm) to the manifold. (This will be the same setup as for the tracer tests.) Make sure the pump has adequate flow and does not leak at the system pressure.
4. Connect the helium source to the manifold near the extraction point and add helium at the prescribed rate using a calibrated flow meter.
5. Monitor tracer concentration in the extraction system until it stabilizes. (This should take only a few minutes.) This value represents the "100 percent recovery" concentration.

c. Vacuum Survey

It is important to collect subsurface vacuum data prior to initiation of the tracer tests. These data provide insight into the general nature of the flow system. For example, if little or no vacuum is recorded at a monitoring point, it can be expected that there is little flow at that point. Large vacuums may indicate areas of active flow; however, these values can also occur within low-flow regions adjacent to higher flow regions. Nevertheless, these data can frequently be helpful in understanding the general nature of airflow at the site.

The general approach will be to measure soil vacuum with MagnehelicTM gauges. The same measurements can be made with a manometer or other calibrated vacuum gauge. For most sites it will be necessary to have gauges in the following ranges (in inches of water): 0 to 1 inch, 0 to 10 inches, and 0 to 100 inches.

Determination of tracer injection rate

Approximate SVE Flow rate = 35 scfm = 1000 L/min

Tracer concentration = 100%

Desired final concentration = 1.0%

Need a dilution of 10^2

Tracer flow rate = $1000 \text{ L/min} / 10^2 = 10 \text{ L/min}$

Calculation of "100 percent recovery" concentration:

To determine the concentration which corresponds to 100 percent recovery, pure helium is injected into the extraction manifold at the same rate (e.g., 10 L/min) that will be used during the tracer test. The helium concentration observed under these conditions is considered to be the value which corresponds to 100 percent recovery.

When the remediation system has been operating for more than one day, determine the soil vacuum at each point in the system by connecting the appropriate gauge to the point. After connection to the monitoring point, sufficient time should be allowed for the vacuum to stabilize (commonly 1 minute).

d. Measurement of Background Helium Concentrations

In most cases, background concentrations of helium will be essentially zero. However, it is important to make that determination prior to starting any test. These measurements can be made while the extraction system is in continuous operation. If previous tracer tests have been conducted at the site, initial concentrations may be non-zero. If concentrations are decreasing with time (i.e., on the tail of the previous test), then if possible, conditions should be allowed to stabilize prior to initiation of the next test. If it is not practical to wait for stabilization prior to initiating the test, the volume of injected tracer can be increased. However, helium concentrations in the influent air should be kept below 5 percent.

e. Estimation of the Rate of Pure Helium to be Injected

A volume fraction of helium in the effluent stream in the range of 0.002 to 0.01 (0.2 to 1 percent) is desired. To estimate the rate of helium injection necessary to produce this concentration, some initial estimate of SVE air flow must be made. The input rate for helium is simply the approximate SVE air flow rate times the target volume fraction. If the IAS rate is low (e.g., <20 percent of the SVE rate), the target effluent volume fraction should be kept at the bottom end of the range to avoid buoyancy effects in the injection air (i.e., helium concentrations in the influent air should be kept below ~5 percent).

f. Introduction of Helium into the Subsurface

Once the preliminary data have been collected and the analytical instrument is calibrated, the tracer test can be initiated. The AS/SVE system should have been in operation for a period of several days prior to initiation of the tracer test. The first step is to start the analytical instrument and determine the initial helium concentration in the subsurface. If these concentrations are adequately low, the helium source can be connected to the IAS well and the test initiated.

g. Sample Collection

Samples should be collected prior to the extraction pump to avoid dilution and other errors which may occur in the extraction pump. Samples can be collected after the extraction pump if the system is correctly calibrated; however, that procedure will not be discussed here.) The pressure at this point will be below atmospheric, so care must be taken to insure that a good sample is collected. In general, samples can be taken from the extraction manifold using a good quality diaphragm pump or metal bellows pump, or manually by syringe. (Once again, care should be taken to insure that the pump does not leak and introduce dilution air.) Pressures below 0.5 atm require extreme care to insure that a good sample is collected. In high-vacuum situations, the capacity of the pump on the helium detector may exceed the capacity of the sample pump. This problem must be addressed by using a sampling pump with adequate capacity.

6. Data Analysis

a. Calculation of Recovery Efficiency at a Particular Point in Time

Recovery efficiency is simply calculated as the ratio of the observed concentrations to the "100 percent recovery" concentration determined at the beginning of the test (Example Calculation A-2),

Example Calculation A-2

Calculation of expected concentration and recovery efficiency

SVE flow rate = 1000 L/min (~35 scfm)

Injection rate of pure helium = 10 L/min

Expected concentration = 1% by volume

Observed concentration ~0.65%

Recovery efficiency $.65/1 \times 100 = 65\%$

b. Time-Series Analysis of Recovery Data

In most cases helium will begin to be recovered within an hour of the initiation of tracer injection. Helium concentrations can be expected to rise rapidly initially and then to asymptotically approach some final value. It may be necessary to continue the test for a period of 24 hours or more to establish the final value of recovery efficiency.

c. Interpretation of the Recovery Efficiency Data

Recovery efficiencies of less than 100 percent imply that some of the AS air is escaping the SVE system. The significance of the lost air will depend upon the potential risks posed by off-site migration of the sparge air. There is, of course, some uncertainty in the measurement of recovery efficiency. That uncertainty stems from uncertainty in flow measurements (injected helium, extracted air) and measured helium concentrations. In this context, recoveries of greater than 80 percent probably indicate adequate recovery, and efficiencies of less than 50 percent generally indicate incomplete recovery.

7. References

Hinchee, R. E., S. K. Ong, R. N. Miller, D. C. Downey, and R. Frandt. 1992. Test Plan and Technical Protocol for a Field Treatability Test for Bioventing. Prepared for the U.S. Air Force Center for Environmental Excellence. Revision 2, May 1992.

APPENDIX D

USE OF A SF6-BASED DIAGNOSTIC TOOL FOR ASSESSING AIR DISTRIBUTIONS AND OXGEN TRANSEFER RATES DURING IAS OPERATION

Use of an SF₆-Based Diagnostic Tool for Assessing Air Distributions and Oxygen Transfer Rates during IAS Operation

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Abstract: A diagnostic test designed to assess air distribution and oxygen delivery rate to the aquifer during in situ air sparging (IAS) is described. The conservative tracer gas, sulfur hexafluoride (SF₆), is added upstream of the air injection manifold during steady IAS operation and groundwater samples are collected from the target treatment zone after some time period (usually 4 to 24 h). The appearance of SF₆ in groundwater is used to characterize the air distribution in the target treatment zone, while the SF₆ concentration increase with time is used to assess oxygen transfer rates to the target treatment zone. Conversion from SF₆ concentration to oxygen mass transfer rate involves correcting the SF₆ concentration increase over time for differences in the relevant chemical properties and injection air concentration. Data presented from a field demonstration site illustrate the utility of this test for identifying air distribution details not readily identified by deep vadose zone helium and groundwater pressure transducer response tests. Oxygen transfer rates at this site ranged from 0 to 20 mg-O₂/L-H₂O/d. Finally, a comparison of short-term SF₆ test data with longer-term dissolved oxygen data illustrated this test's utility for anticipating long-term dissolved oxygen distributions.

Introduction

In situ air sparging (IAS) is used for the treatment of contaminated aquifers. It has been employed as a source zone and a dissolved plume treatment option, a chemical migration barrier, and as a component of other remediation systems requiring gas delivery of oxygen, nutrients, or other reactants. It is most commonly employed at petroleum hydrocarbon spill sites, but is also used frequently at chlorinated hydrocarbon spill sites. IAS systems are often coupled with soil vapor extraction (SVE) systems for capture of liberated contaminant vapors. A detailed summary of published IAS studies can be found in P.C. Johnson et al. (2001a).

The complexity of the processes involved makes it difficult to anticipate IAS performance (P.C. Johnson et al., 2001a). For example, performance is strongly dependent on air distribution in the target treatment zone, and air distribution is very sensitive to subtle changes in soil structure. Recognizing this, P.C. Johnson et al. (2001b) propose a design paradigm that emphasizes characterization of air distribution at the pilot-

and full-scale, as well as use of diagnostic tools for full-scale performance assessment and optimization.

Air distribution can be inferred qualitatively from indirect measurements, such as transient pressure responses (R.L. Johnson et al., 2001a) and deep vadose zone helium measurements (R.L. Johnson et al., 2001b). It can also be assessed directly at discrete points with the use of dissolved oxygen measurements. However, Johnson et al. (1997) point out that short-term test (<24 h) oxygen measurements can be misleading, as measurable increases in dissolved oxygen (DO) levels sometimes occur only after periods of days to weeks due to oxygen demand within the aquifer. Given the advantages and limitations of each individual test, it has been recommended that a suite of techniques be used to assess air distribution (P.C. Johnson et al., 2001b; R.L. Johnson et al., 2001b). The approach described here is complimentary to the methods identified above. Like DO measurement, it provides a direct measurement of air distribution in the target treatment zone at discrete points. This method is a modification of the approach presented by Johnson et al. (1996). It

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uses a tracer compound and is more sensitive than DO measurement as it can identify areas where oxygen delivery is occurring even though DO levels are unchanged in the short-term.

With respect to performance monitoring and IAS system optimization, conventional monitoring plans provide little opportunity for the real-time performance assessment and optimization called for in the design paradigm mentioned above. Practitioners currently rely on quarterly (or less frequent) groundwater monitoring, and then performance is judged by changes in the dissolved concentrations over periods of months to years. With only these data, optimization of IAS systems is impracticable because conclusions regarding performance can only be drawn after collecting data over time intervals that are comparable to the overall remediation time frame (months to years). Without system optimization, many systems may operate longer than is necessary, and many systems may be terminated prior to achieving their full potential for remediation. In fact, the overall performance of IAS systems has been quite variable to date, and there is little evidence that system optimization is a component of conventional practice (Bass and Brown, 1995).

One of the attractive features of the SF₆ method described here is that it has dual utility. It can be used to assess air distribution and it can also be used to provide near real-time measurements of oxygen transfer rate. Knowledge of oxygen transfer rate is especially important when treating aerobically biodegradable contaminants; rates can be used to estimate remediation time frames, and it is desirable to maximize these rates throughout the target treatment zone. Oxygen transfer rates can be determined within 4 to 24 h with this method, so it can be used for system performance assessment and optimization. The authors are unaware of any other diagnostic tools for uses such as this, other than the complementary push-pull diagnostic test described by Amerson et al. (2001).

Diagnostic Tool Methodology

Overview

Application of the SF₆ diagnostic tool is illustrated schematically in Figure 1. During either IAS pilot-test or full-scale operation, a nonreactive gas tracer is metered into the air injection manifold at a constant rate. As the air-tracer mixture flows through gas channels in the aquifer, tracer partitions into groundwater and moves away from the air channel-groundwater interface through the combination of diffusion and dispersion/advection. After a period of constant injection (usually 4 to 24 hours), groundwater within the

target treatment zone is sampled at locations of interest and dissolved tracer concentrations (C_{tracer} [mg/L]) are measured.

Dissolved tracer concentration in equilibrium with the injection air stream ($C_{\text{tracer}}^{\text{max}}$ [mg/L]) is also measured. This is accomplished by bubbling a slip-stream of the injection air/tracer mixture through a groundwater sample as shown in Figure 1, and then measuring the dissolved tracer concentration in that sample.

Data Reduction

Given the short duration of the test, the presence of tracer in a groundwater sample is interpreted qualitatively to be an indication of the presence of gas channels within the sampling volume. Higher concentrations might also be interpreted to suggest a higher density of air flow channels.

Oxygen and tracer are delivered to the subsurface in the injected air stream, and then they both partition to groundwater. Differences in delivery rates occur as a result of differences in concentration in the injected gas stream and differences in chemical properties. Theory suggests that the delivery rate is limited by water-phase diffusion processes (e.g., Ahlfeld et al., 1994; Johnson, 1998). In this case one can approximate the mass transfer rate for a chemical i $\langle m_i \rangle$ [mg/d]:

$$\langle m_i \rangle = A \left(\frac{D_i}{\delta} \right) C_i^{\text{max}} \quad (1)$$

where A is the interfacial area [m²], D_i is the diffusion coefficient for the chemical in water [m²/d], δ is the diffusion path length [m], and C_i^{max} [mg/m³] is the dissolved chemical concentration in equilibrium with the gas phase concentration at the air-water interface. As A and δ should be the same for all chemicals, we use Equation 1 to write:

$$\frac{\langle m_o \rangle}{\langle m_{\text{tracer}} \rangle} = \left(\frac{D_o}{D_{\text{tracer}}} \right) \left(\frac{C_o^{\text{max}}}{C_{\text{tracer}}^{\text{max}}} \right) \quad (2)$$

The subscripts "o" and "tracer" refer to oxygen and the tracer, respectively. This expression can be rearranged for the case where $\langle m_{\text{tracer}} \rangle$ is known and $\langle m_o \rangle$ is desired:

$$\langle m_o \rangle = \left(\frac{D_o}{D_{\text{tracer}}} \right) \left(\frac{C_o^{\text{max}}}{C_{\text{tracer}}^{\text{max}}} \right) \langle m_{\text{tracer}} \rangle \quad (3)$$

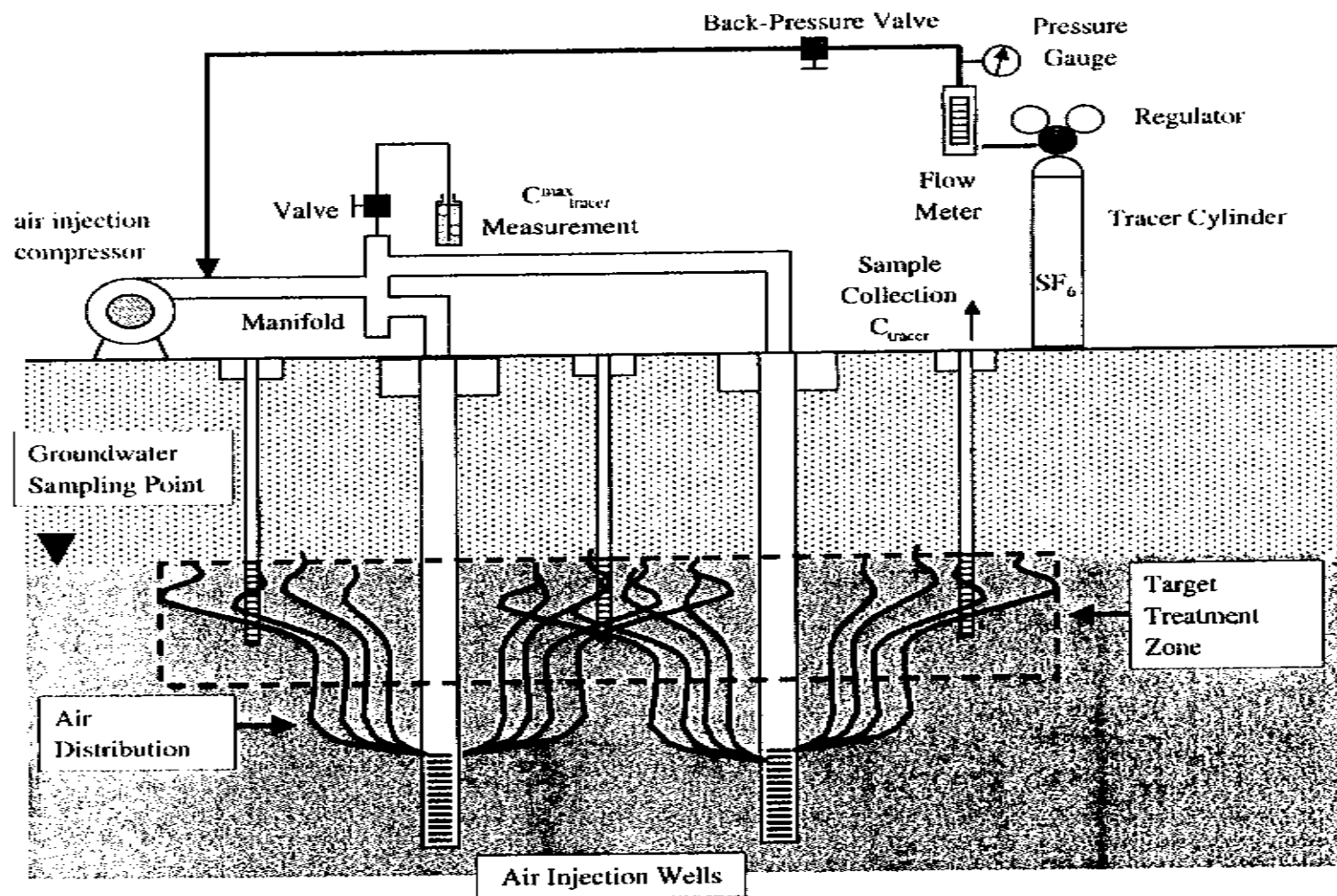


Figure 1. Diagnostic test schematic.

Using experimental data, the time-averaged tracer transfer rate to a given sampling volume is calculated from the measured concentration increase C_{tracer} [mg/L], the sampling volume V [L], and the tracer injection duration T [d]:

$$\langle m_{\text{tracer}} \rangle = \frac{C_{\text{tracer}} V}{T} \quad (4)$$

Therefore, the time-averaged oxygen mass transfer rate to the sampling volume can be written:

$$\langle m_o \rangle = \left(\frac{C_{\text{tracer}}}{C_{\text{tracer}}^{\text{max}}} \right) \left(\frac{D_o}{D_{\text{tracer}}} \right) \frac{C_o^{\text{max}} V}{T} \quad (5)$$

The mass transfer rate can also be expressed as a rate per unit volume m^* [mg-O₂/L-H₂O/d]:

$$m^* = \frac{\langle m_o \rangle}{V} = \left(\frac{C_{\text{tracer}}}{C_{\text{tracer}}^{\text{max}}} \right) \left(\frac{D_o}{D_{\text{tracer}}} \right) \frac{C_o^{\text{max}}}{T} \quad (6)$$

Diffusion coefficients in water for some chemicals are tabulated, and others can be estimated from empirical relationships (Bird et al., 1960). Given the approximate nature of this theoretical analysis and the observation that many diffusion coefficients in water fall in the range of 1 to 2×10^{-5} cm²/s, the ratio of diffusion coefficients in water can be treated as unity.

In summary, this analysis is based on the assumption that oxygen and SF₆ transfer processes are similar and that the rates are proportional to the equilibrium air channel-groundwater interface concentration and the molecular diffusion coefficient in water. This calculation also assumes that both species are nonreactive, whereas oxygen is likely to be consumed at sites where aerobic biodegradation reactions occur. Thus, it can be argued that this calculation might underestimate the actual time-averaged oxygen delivery rates to an aquifer as the driving force for mass transfer (concentration gradients) would be higher under conditions where a chemical was being consumed. Furthermore, it is important to note that the rate estimate obtained from this methodology is a time-averaged quantity, and consequently mass transfer rate estimates will be greatest for data from shorter tests when the concentration difference between C_{tracer} and $C_{\text{tracer}}^{\text{max}}$ is large. Admittedly, this method of analysis is simplistic, but we believe that the approach should provide reasonable order-of-magnitude estimates of oxygen delivery rates. Other than the push-pull test described by Amerson et al. (2001), this is the only tool currently available for obtaining this information.

Tracer Selection

SF₆ was the tracer initially selected for testing of this diagnostic tool. SF₆ is a gas at standard conditions; it is also a nondegrading and a nonreacting compound at typical environmental conditions. It is commonly used to trace leaks in ventilation and mine-face systems and has also been applied to groundwater and geothermal investigations. It is sparingly soluble in water and has a Henry's Law constant much greater than unity (approximately 150 mg/L-air/mg/L-H₂O; Amerson 1997). SF₆ is detectable in the low parts-per-trillion by volume (ppt_v) range with the use of a specialized SF₆ detector (Lagus Applied Technologies, Torrance, CA) or other gas chromatograph (GC) equipped with an electron capture detector (ECD). SF₆ was selected for this work because its large Henry's Law constant makes analysis from groundwater samples relatively simple and because it can be detected at such low concentrations. It can be added at low parts-per-million by volume (ppm_v) concentrations to the air injection manifold and this greatly reduces the volume of tracer gas required for the test. Both oxygen and SF₆ partition to trapped gas in aquifers to a similar degree and both partition to nonaqueous phase liquid (NAPL). The effect of partitioning to NAPL on the results of this test is not understood at this time.

Diagnostic Test Procedures

A sample test protocol is given below. It is followed by a discussion of procedures and calculations specific to the use of SF₆. The test is conducted only after the IAS system is operating at steady conditions.

1. Determine the desired groundwater extraction volume based on how large a volume of aquifer is to be assessed about each sampling point. In this work groundwater samples were obtained from small volume discrete-depth samplers and the volume was typically <1 L.
2. Prior to tracer injection, collect groundwater samples for baseline tracer concentration measurements. At least one well-borehole volume is purged prior to sampling. It is critical that groundwater samples be collected without causing gas bubbling through the sample as this can affect dissolved tracer concentrations. Dissolved oxygen (DO) concentrations can also be measured at this time.
3. Based on the baseline tracer concentrations, determine the target tracer concentration in the injection air. To be consistent with the mathematical analysis and to ensure a reasonable dynamic measurement range, the injection air tracer concentration should be high

- enough that $C_{\text{tracer}}^{\text{max}}$ is at least 100 times greater than the baseline concentration.
4. Attach the tracer gas line to the air injection line at least ten pipe diameters upstream of the manifold connecting all air injection wells to allow adequate mixing.
 5. Initiate flow of tracer at the target injection rate; use a back-pressure valve to adjust the tracer gas pressure at the flow meter to at least 15 psig above the pressure in the air line to minimize effects of air injection line pressure fluctuations on the tracer delivery rate.
 6. Using the slip-stream valve on the air injection manifold (see Figure 1), bubble the air stream vigorously through a 40 mL VOA vial containing initially tracer-free groundwater for about 2 minutes, then analyze and compare with the target $C_{\text{tracer}}^{\text{max}}$ value. Adjust the tracer injection rate as necessary and repeat this step until the target concentration is achieved.
 7. Allow the tracer gas to flow at a constant rate into the air injection line and keep the IAS system running 4 to 24 hours.
 8. Collect the desired volume of groundwater from the sampling points/wells, mix, and then fill a VOA vial (allowing no headspace in the sample) with a sample from this larger volume.
 9. Analyze dissolved tracer concentrations for all samples and analyze data as discussed above (see Equation 6).

SF₆ – Specific Methods and Procedures

Groundwater SF₆ concentrations are determined using a headspace technique coupled with GC-ECD analysis. In brief, groundwater samples are collected in zero-headspace 40 mL VOA vials. Using two syringes, a volume V_w (usually 1 mL) of the groundwater sample is removed into one syringe by pressure displacement using a second syringe containing SF₆-free water. The groundwater sample is then injected into a sealed and empty 40 mL VOA vial that has been purged with UHP nitrogen and sealed. An additional 5 mL of UHP nitrogen is added through the septum and the vial is shaken vigorously. Then 5 mL of the headspace is withdrawn and injected into the GC-ECD for analysis. The large Henry's Law constant for SF₆ ensures essentially complete partitioning of the SF₆ from groundwater into the vial headspace (>99.9% for these conditions). The original dissolved concentration C_{tracer} and the measured headspace concentration C_{HS} are related by:

$$C_{\text{tracer}} = \frac{V_{\text{HS}}}{V_w} C_{\text{HS}} \quad (7)$$

where V_{HS} and V_w denote the headspace volume and volume of water in the nitrogen-purged vial. It is possible to analyze one groundwater sample approximately every 5 minutes with this approach.

It is important to note that the vial purge steps are extremely important as the concentration of SF₆ in ambient air increases during the test and this can cause cross-contamination of samples. Also, in some areas, industry emissions of SF₆ are significant enough that ambient air contains SF₆ at concentrations in the low ppb_v range.

As mentioned above, the target injection rate for SF₆ into the IAS injection air stream is determined based on the baseline SF₆ concentrations in groundwater. Instrument detection limits also need to be considered. In this work a specialized SF₆ detector having a linear response range of about 0.01 to 50 ppb_v was used. To make best use of the instrument's dynamic range and to avoid saturating the detector, it was decided that the SF₆ injection rates should be adjusted so that maximum measured headspace SF₆ concentration $C_{\text{tracer}}^{\text{max}}$ would be about 10 ppb_v.

Knowledge of the baseline tracer concentration in groundwater, the target maximum headspace concentration and Equation 7 determine the minimum ratio V_{HS}/V_w to be used in the analysis. The target SF₆ injection rate Q_{SF_6} [ft³/min] is calculated using Equation 7 and Henry's Law:

$$Q_{\text{SF}_6} = Q_{\text{air}} H C_{\text{HS}}^{\text{max}} [\text{ppb}_v] \left(\frac{V_{\text{HS}}}{V_w} \right) \times 10^{-9} \quad (8)$$

where $C_{\text{HS}}^{\text{max}}$ is the maximum target headspace concentration [ppb_v]; Q_{SF_6} is the injection rate of SF₆ [ft³/min]; Q_{air} is the total injection rate of SF₆ + air [ft³/min]; H is the SF₆ Henry's Law constant [150 (mg/L-air)/(mg/L-H₂O)]; V_w is the volume of groundwater used in analysis [mL]; and V_{HS} is the volume of headspace used in analysis [mL].

For example, for an IAS system with a total injection rate of $Q_{\text{air}}=100$ ft³/min, a target headspace concentration of $C_{\text{tracer}}^{\text{max}}=10$ ppb_v, $V_w=1$ mL and $V_{\text{HS}}=39$ mL, the target injection rate of SF₆ is $Q_{\text{SF}_6}=165$ mL/min [=0.006 ft³/min].

Finally, it should be noted that if one wishes to conduct multiple tests separated by relatively short periods of time (e.g., days to weeks), then it is prudent to conduct the initial test at a lower target

concentration and then increase the target concentration by about an order of magnitude or more for each successive test.

Application of the Diagnostic Test

Field Site Description

The diagnostic test was initially applied at the Hydrocarbon National Test Site (HNTS) located at the U.S. Naval Construction Battalion Center in Port Hueneme, California. At the HNTS, groundwater had been impacted by a relatively large gasoline release from the Base service station. The push-pull test was applied to a 20-m \times 20-m IAS study area located within a larger (approximately 50 m \times 300 m) residual immiscible hydrocarbon source zone. This study area was equipped with an extensive monitoring network, and the site hydrogeology and contaminant distribution were already well characterized.

A plan-view schematic diagram of the test site monitoring network is shown in Figure 2. The monitoring system included 12 multilevel monitoring installations, each containing a bundle of 15 0.32-cm inner diameter (ID) (1/8-inch) color-coded, stainless steel sampling lines with ports at 0.6, 1.2, 1.8, 2.4, 3.0, 3.4, 3.7, 4.0, 4.3, 4.6, 4.9, 5.2, 5.5, 5.8, and 6.1 m (2, 4, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19 ft) below ground surface (BGS). The groundwater table was at approximately 3-m (10 ft) below ground surface, and the immiscible hydrocarbon smear zone extended from approximately 3 to 4 m (10 to 13 ft) BGS. Dissolved total hydrocarbon concentrations in the smear zone generally exceeded 1 mg/L. The IAS well was screened from 5.8 to 6.1 m (18 to 20 ft) BGS. Previous studies have shown that the air distribution in the aquifer is nonuniform about the air injection point, exhibiting tendencies to flow along the axis defined by MP6, MP12, MP3, and MP9 well (R.L. Johnson et al., 2001b).

The SF₆ diagnostic test was applied during the pilot study at an IAS air injection flow rate of 570 standard L/min (20 standard cubic feet per minute[scfm]).

Assessing Air Distribution

Table 1 presents the dissolved SF₆ concentrations resulting after 24 h of SF₆ injection. The concentrations are expressed as saturations ($=C_{\text{tracer}}/C_{\text{tracer}}^{\text{max}} \times 100\%$). While measurements have been made and are reported from 3.0 to 5.8 m BGS, the target treatment zone at this site is the 3.0 to 4.0 m BGS interval.

Overall, the SF₆ data set shows a nonsymmetrical and irregular air distribution. High saturations at MP1, MP2, and MP3 suggest that air leaving the IAS well

initially flows upward within 1.5 m of the injection well as it moves toward the water table. This behavior is to be expected in relatively homogeneous sandy aquifers (P.C. Johnson et al., 2001a). What is unusual is that some of the air flow becomes stratified at a depth of about 4 to 4.5 m BGS, and it moves preferentially along the axis roughly defined by MP9 and MP12. This hypothesis is supported by the high saturations at MP3, MP6, MP9, and MP12 in the upper part of the aquifer (3 to 4 m BGS) and low saturations at other points. For reference, the air distribution at the water table suggested by this data is similar to the distribution inferred from deep soil gas helium data at this site (R.L. Johnson et al., 2001b).

O₂ Mass Transfer Rates

Table 2 contains the 24-h average oxygen mass transfer calculated from the data in Table 1. The oxygen mass transfer rates range from about 0 to 20 mg-O₂/L-H₂O/d. Assuming a stoichiometry of 3 mg-oxygen required per mg of hydrocarbon, the IAS system can support aerobic biodegradation rates ranging from 0 to 7 mg-hydrocarbon/L-H₂O/d, with these rates being spatially distributed as shown in Table 2.

Comparison of Short-Term SF₆ Distribution with Longer-Term Dissolved Oxygen Distribution

DO measurements were made after 7 d of 20 ft³/min air injection. Prior to this, the pilot system had been operated for 14 consecutive days; 7 d at 5 ft³/min and 7 d at 10 ft³/min. It is useful to compare the short-term SF₆ distribution with the longer-term DO distribution to gain some insight as to how well the short-term diagnostic test results relate to longer-term DO distributions.

Table 3 presents the DO concentrations expressed as saturations ($=C/C_{\text{max}} \times 100\%$). In comparing Table 1 and Table 3, we look for qualitative similarities in the spatial distributions and not quantitative agreement with the saturations. Overall, both suggest asymmetric air distribution, with little oxygen delivery in the treatment zone at MP1, MP5, MP7, MP10, and MP11.

With respect to differences between the two, oxygen increases have occurred in the target treatment zone at MP4 and MP8. Also of interest are the increases in DO levels below the treatment zone in areas that SF₆ data suggest are not directly affected by air flow. These DO increases could be the result of groundwater advection and vertical dispersion from areas of air flow combined with little oxygen demand (as this zone lies below hydrocarbon-impacted soils).

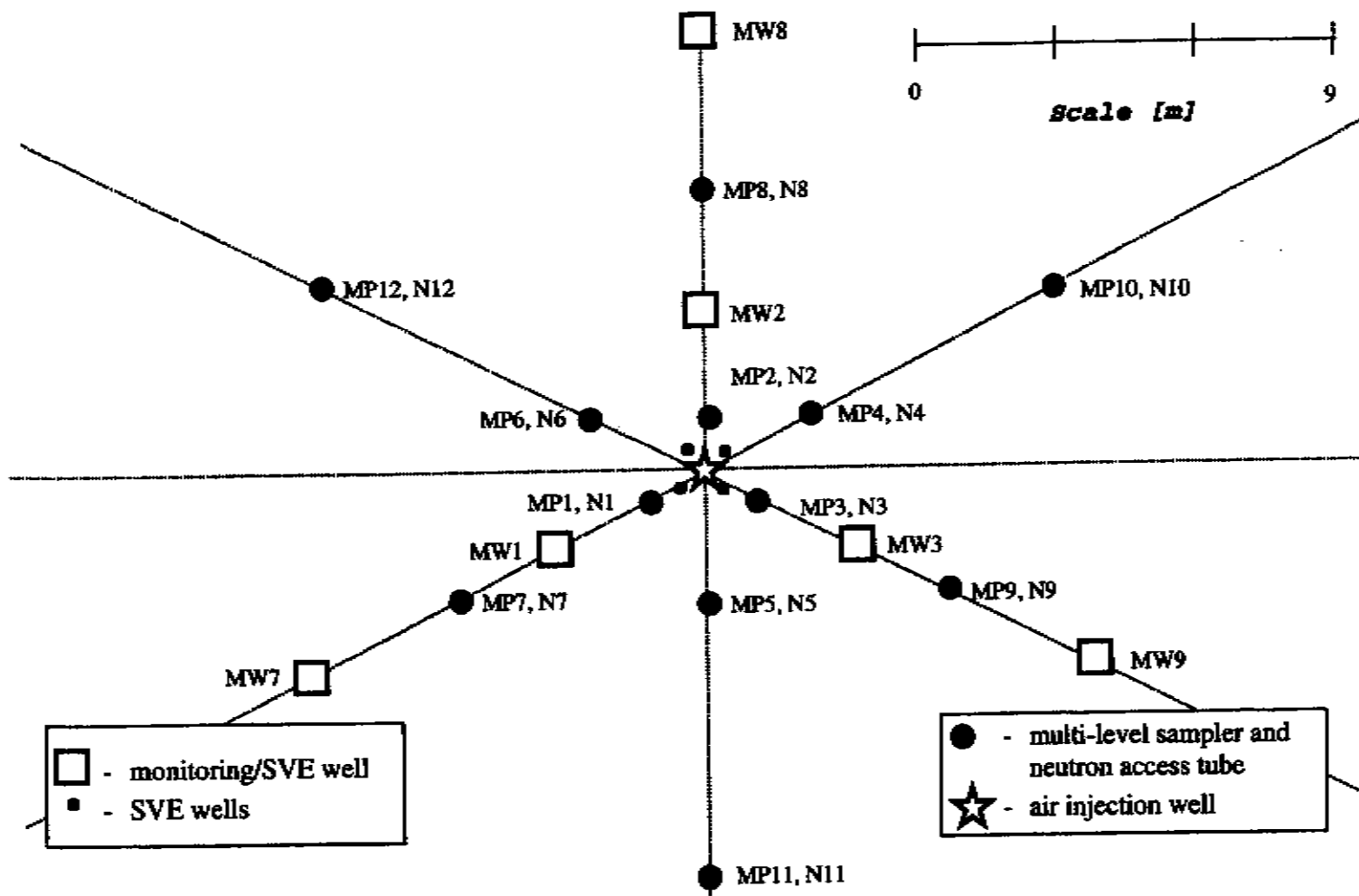


Figure 2. IAS test plot set-up at the Port Hueneme, CA HNTS Site.

Table 1. SF₆ saturations [$C_{\text{tracer}}/C_{\text{max, tracer}} \times 100\%$] after 24 h of continuous SF₆ injection during the 20 SCFM IAS pilot test [ns — groundwater samples not collected at this point as gas was recovered instead of water — the SF₆ saturation is assumed to be 100% at these points].

Distance Below Ground Surface [m]												
	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP11	MP12
3.0	4	90	0	1	0	31	0	0	72	0	0	2
3.4	6	100	2	2	0	54	0	1	82	1	0	1
3.7	1	58	31	6	0	ns	0	1	4	1	0	20
4.0	2	97	3	0	1	23	0	0	12	4	0	3
4.3	16	43	32	0	1	47	0	1	3	2	0	0
4.6	5	ns	22	5	4	38	0	1	0	0	0	0
4.9	2	36	16	0	0	0	0	2	0	1	0	ns
5.2	61	0	8	0	0	0	0	2	0	0	0	0
5.5	1	0	1	0	1	0	0	1	0	1	0	0
5.8	3	0	0	0	0	1	0	0	0	0	0	2
	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP11	MP12
	<div> <div>← 1.5 →</div> <div>← 3 →</div> <div>← 6 →</div> <div>← 9 →</div> </div>											
	Distance from Sparge Well [m]											

Table 2. 24-hour average oxygen mass transfer rates [$\text{mg-O}_2/\text{L-H}_2\text{O/d}$] calculated from SF_6 data during the 20 SCFM IAS pilot test [ns — groundwater samples not collected at this point as gas was recovered instead of water]

Distance Below Ground Surface [m]	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP11	MP12
3.0	0.7	17.4	0.1	0.2	0.0	5.9	0.0	0.1	13.9	0.1	0.1	0.4
3.4	1.1	19.2	0.4	0.3	0.0	10.3	0.0	0.1	15.7	0.1	0.1	0.3
3.7	0.2	11.1	5.9	1.2	0.0	ns	0.0	0.2	0.7	0.1	0.0	3.8
4.0	0.3	18.6	0.6	0.0	0.1	4.4	0.0	0.0	2.2	0.7	0.1	0.6
4.3	3.2	8.3	6.2	0.0	0.1	8.9	0.0	0.1	0.6	0.3	0.0	0.0
4.6	0.9	ns	4.2	0.9	0.8	7.4	0.0	0.1	0.1	0.1	0.0	0.1
4.9	0.4	6.9	3.1	0.0	0.0	0.1	0.0	0.4	0.1	0.1	0.1	ns
5.2	11.7	0.0	1.6	0.1	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
5.5	0.2	0.0	0.2	0.0	0.3	0.1	0.0	0.2	0.0	0.3	0.1	0.0
5.8	0.5	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.4
	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP11	MP12
	← 1.5 →		← 3 →			← 6 →			← 9 →			
	Distance from Sparge Well [m]											

Table 3. Longer-term O_2 saturations [$C/C^{sat}_o \times 100\%$] after 3 weeks of continuous IAS operation at 5 SCFM (7 d), 10 SCFM (7 d), and then 20 SCFM (7 d) air injection rates [0 values are assigned to all points where dissolved oxygen readings are <1 mg/L; points where gas was withdrawn from sampling point are labeled "air" — O_2 saturations are assumed to be 100% at these points].

Distance Below Ground Surface [m]	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP11	MP12
3.0	0	44	22	0	0	72	0	33	86	63	0	0
3.4	0	0	0	50	0	76	0	53	68	0	0	0
3.7	0	83	57	78	30	air	0	30	43	0	0	32
4.0	0	78	0	68	0	39	0	76	76	0	0	40
4.3	54	83	80	76	48	74	0	0	66	0	0	24
4.6	28	air	82	66	48	72	0	24	0	0	22	47
4.9	0	0	80	72	60	0	0	26	30	0	33	air
5.2	0	44	87	air	61	30	0	0	0	56	33	0
5.5	0	0	26	0	52	0	0	23	24	58	28	0
5.8	0	0	0	0	0	0	0	28	56	air	50	89
	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP11	MP12
	← 1.5 →		← 3 →			← 6 →			← 9 →			→
	Distance from Sparge Well [m]											

Summary

In summary, a gas-tracer diagnostic test for IAS systems has been developed and tested. This test is attractive because of its dual nature; it is useful for assessment of air distributions and oxygen mass transfer rates. The test can be conducted in a relatively short period of time and therefore is useful for pilot test air distribution characterization and full-scale system optimization. By monitoring changes in dissolved SF_6 distributions and oxygen transfer rates with changes in system operation and design, IAS system performance can be optimized. To date, no other short-term diagnostic tools have been developed for IAS system optimization.

Data presented from the initial application illustrate its utility in identifying air distribution details not readily identified by deep vadose zone helium and groundwater pressure transducer response tests. Oxygen transfer rates at this site ranged from 0 to 20 $\text{mg-O}_2/\text{L-H}_2\text{O/d}$, and this information is valuable for assessing potential significance of contaminant removal via aerobic biodegradation. Actual aerobic biodegradation rates could not exceed rates calculated from the oxygen delivery rates. Measurements at other sites not discussed here have ranged from 0 to 150 $\text{mg-O}_2/\text{L-H}_2\text{O/d}$. Finally, a comparison of short-term SF_6 test data with the longer-term dissolved oxygen data illustrated the utility of this short-term test for assessing long-term dissolved oxygen distribution.

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